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Operational Safety: "The Platform Manager's Risk Control Tool"

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Marine Technology
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PREFACE

The following report is the master's thesis written in partial fulfilment of the MSc program in Marine Technology, with a focus on Marine systems and Operation Technology at the Department of Marine Technology (IMT) at the Norwegian University of Science and Technology (NTNU), in cooperation with Det Norske Veritas (DNV). The thesis was written during the spring semester of 2013. The topic of the thesis, Operational Safety: "The Platform Manager's Risk Control Tool", was proposed by DNV and further developed in cooperation with professor Jan Erik Vinnem at IMT.

Trondheim, May 21, 2013

Christian Skogheim Madsen

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C.S.M.

EXECUTIVE SUMMARY

Avoiding accidents is important, especially in the petroleum industry where the outcome of a major accident can be serious harm to both people, the environment and to company property. There are requirements from the Petroleum Safety Authority [Norway] (PSAN), as well as from internal guidelines from operators on the Norwegian Continental Shelf, that barriers are established and maintained so that the probability of accident situations developing is reduced, and that harm and disadvantages are limited. Furthermore, it is required that the operators are aware of the condition of the safety barriers, i.e. if the barriers have been impaired or are non-functioning. As a result of the Macondo disaster, PSAN has identified the need to develop new tools for risk management. In addition, a questionnaire survey carried out for PSAN as a supervisory activity in 2009 revealed the need for the development of such tools, as it showed that the current risk analysis studies employed by the sector were not utilised "as input to day-to-day decisions on installations/plants about minor modifications, maintenance and intervention activities" (Vinnem and Haugen, 2012, p. 4).

This master's thesis explores and describes how barrier management can be directly linked to operational control of major accident risk. An extensive review of literature and several interviews are performed to examine how the platform manager can use information on the state of the safety barriers as a risk control tool. The thesis describes the premises for a new risk control tool including, but not limited to, its purpose, expectations and requirements to the tool, situations of use, how information should be communicated, a description of the type of information that goes into the risk control tool, the data sources of such information and the output it provides. Moreover, interviews with two former platform managers and an executive vice president are performed to present the most important decisions the management of the platform makes where the information on barrier condition is of importance, as well as how risk considerations come into these decisions. Furthermore, existing measures, methods and tools are presented, including a method for considering the total risk on the platform against acceptance criteria for risk. Finally, based on contact with the petroleum industry and a classification society, the thesis presents how decision-making criteria can be set for the activities that are not permitted based on, amongst other, information on the state of the safety barriers.

Based on these examinations, the following suggestions are made:

- A new risk control tool should be developed with the purpose of providing decision support, including amongst other decision-making criteria and information on safety barrier condition, to situations where the management of the platform is to decide whether or not an activity can be performed.
- A new risk control tool should be focused on bridging gaps found in the industry it is intended for. A new risk control tool should thus be focused on providing decision support on a day-to-day basis to platform manager(s), as well as to onshore management on a long-term basis, during planning of activities on the installation where the information on the state of safety barriers is of importance.
- The tool itself should be a robust information surface with an interface built up like other tools used in the industry or by a specific company.
- The user(s) of the tool should be presented with; area specific information on the state of the safety barriers that are directed against major accidents, relevant indicators and information that is suitable for helping the decision-maker make a decision including, but not limited to, valve status from automatic transponders, a "map" of the platform showing relevant information, current weather and weather forecast, operational data, operating limits and preconditions used in QRA, preconditions stipulated and risk considerations performed during the onshore planning of activities, decision-making criteria and guidance, a simulation function where the user(s) can simulate the effect a specific activity brings in time and space, and a function for considering the total risk of the platform against tolerance limits for risk.
- A new risk control tool should, as far as possible, rely on and take advantage of frequently updated and reliable information from systems already put in place by the operator.
- Efforts should be made to be able to present detailed installation specific information of the condition of the safety barriers/-systems.
- A classification of barrier elements according to their transient properties / behaviour could be developed for a risk control tool that is to be capable of capturing and showing the short-term transient behaviour (or state) of the safety barriers.
- Focus should be on technical and organisational safety barriers, which show a more short-term transient behaviour than operational barriers.
- Presented indicators should be limited to a reasonable number, fit the purpose of the risk control tool, and be recognizable for decision-makers and fitting to the installation.

SAMMENDRAG

Å unngå ulykker er viktig, spesielt i petroleumsindustrien der utfallet av en storulykke kan være store skader både på mennesker, miljø og et selskaps eiendom. Det er krav fra Petroleumstilsynet, samt i interne retningslinjer fra operatørene på norsk sokkel, at barrierer er etablert og vedlikeholdes slik at sannsynligheten for at ulykkessituasjoner utvikler seg reduseres, og slik at skader og ulemper begrenses. Videre kreves det at operatørene er kjent med tilstanden til sikkerhetsbarrierene, dvs. om barrierene er svekket eller er ikke-fungerende. Som et resultat av Macondo ulykken har Petroleumstilsynet identifisert et behov for å utvikle nye verktøy for risikostyring. I tillegg viste en spørreundersøkelse, utført for Petroleumstilsynet som tilsynsaktivitet i 2009, et behov for utvikling av slike verktøy ettersom det viste seg at dagens risikoanalysestudier benyttet i sektoren ikke blir benyttet som input til dag-til-dag-beslutninger på installasjoner / anlegg om mindre modifikasjoner, vedlikehold og intervensjonsaktiviteter (Vinnem og Haugen, 2012).

Denne masteroppgaven utforsker og beskriver hvordan barrierestyring kan knyttes direkte opp til operativ kontroll med storulykkesrisiko. En omfattende gjennomgang av litteratur og flere intervjuer er utført for å undersøke hvordan plattformsjefen kan bruke informasjon om tilstanden på sikkerhetsbarrierene som et risikostyringsverktøy. Avhandlingen beskriver premissene for et nytt risikostyringsverktøy inkludert, men ikke begrenset til, dets formål, forventninger og krav til verktøyet, situasjoner for bruk, hvordan informasjon skal kommuniseres, en beskrivelse av hvilken type informasjon som går inn i risikostyringsverktøyet, datakildene til slik informasjon og hva som skal presentere til brukeren. Videre er det utført intervjuer med to tidligere plattformsjefer og en konserndirektør for å presentere de viktigste beslutningene plattformledelsen gjør hvor informasjon om barrieretilstand vil ha betydning, samt hvordan risikobetraktninger kommer inn i disse beslutningene. Videre blir eksisterende tiltak, metoder og verktøy presentert, inkludert en metode for å vurdere totalrisikoen på plattformen mot akseptkriterier for risiko. Deretter presenterer avhandlingen, basert på kontakt med industrien og et klasseselskap, hvordan beslutningskriterier kan settes for aktiviteter som ikke tillates basert på blant annet informasjon om tilstanden til sikkerhetsbarrierene.

På grunnlag av disse undersøkelsene blir følgende forslag gitt:

- Et nytt risikostyringsverktøy bør utvikles med det formål å gi beslutningsstøtte, som blant annet beslutningskriterier og informasjon om tilstand på sikkerhetsbarrierer, til situasjoner hvor plattformledelsen skal avgjøre hvorvidt en aktivitet kan utføres.
- Et nytt risikostyringsverktøy bør være fokusert på å tette hull funnet i bransjen det er beregnet for. Et nytt risikostyringsverktøy bør derfor være fokusert på å gi beslutningsstøtte fra dag til dag til plattformsjef(er), samt til den landbaserte ledelsen på langsiktig basis, under planlegging av aktiviteter på innretningen der informasjon om tilstand på sikkerhetsbarrierene er av betydning.
- Verktøyet i seg selv bør være en robust informasjonsoverflate med et grensesnitt bygget opp som andre verktøy benyttet av industrien eller et bestemt selskap.
- Brukerne av verktøyet bør presenteres med; områdespesifikk informasjon om tilstanden på sikkerhetsbarrierene som er rettet mot storulykker, relevante indikatorer og informasjon som er egnet for å hjelpe beslutningstakeren med å ta en beslutning som for eksempel automatisk ventilstatus fra transpondere, et "kart" over plattformen som viser relevant informasjonen, gjeldende vær og værvarsel, operasjonelle data, operasjonsbegrensninger og forutsetninger brukt i QRA, forutsetninger benyttet og risikovurderinger utført på land under planlegging av aktiviteter, beslutningskriterier og veiledning for vurdering, en simuleringsfunksjon hvor brukeren kan simulere effekten en spesifikk aktivitet bringer i tid og rom, og en funksjon for å vurdere den totale risikoen på plattformen opp mot tillatt toleransegrense for risiko.
- Et nytt risikostyringsverktøy bør, så langt som mulig, dra nytte av hyppig oppdatert og pålitelig informasjon fra systemer som allerede benyttes av operatøren.
- Arbeid bør nedlegges slik at detaljert og installasjonsspesifikk informasjon om tilstanden på sikkerhetsbarrierer kan presenteres.
- En klassifisering av barriereelementer i henhold til deres transiente egenskaper / atferd kan utvikles for et risikostyringsverktøy som skal være i stand til å fange opp og vise den kortsiktige transiente atferden (eller statusen) til sikkerhetsbarrierene.
- Fokus bør være på tekniske og organisatoriske barrierer som viser en mer kortsiktig transient oppførsel enn operasjonelle barrierer.
- Indikatorer presentert gjennom verktøyet bør begrenses til et rimelig antall, være tilpasset formålet til risikostyringsverktøyet, være gjenkjennelig for beslutningstakere og passende til installasjonen.

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"A sound health, safety and environment culture that includes all phases and activity areas shall be encouraged through continuous work to reduce risk and improve health, safety and the environment."

Section 15 of *the Framework Regulations,* PSAN (2011c)

1 INTRODUCTION

1.1 Background

Avoiding accidents is important, especially in the petroleum industry where the outcome of a major accident can be serious harm to both people, the environment and to company property. This applies to the petroleum industry in general, but even more so to platforms standing in harsh conditions like those on the Norwegian Continental Shelf (NCS).

There are requirements from the Petroleum Safety Authority [Norway] (PSAN, 2012b), as well as from internal guidelines from operators on the NCS, that barriers are established and maintained so that the probability of accident situations developing is reduced, and that harm and disadvantages are limited. Furthermore, it is required that the operators are aware of the status of the barriers, i.e. if the barriers have been impaired or are non-functioning (PSAN, 2012b).

If one think about the assets and interests at stake in the petroleum industry, one would think that this industry would be pioneering and outstanding when it comes to safety issues. Still, now and again, we can hear from the media about major accidents happening in the petroleum industry, like for instance the Macondo disaster in April 2010 (Deepwater Horizon Study Group, 2011).

As a result of the Macondo disaster, PSAN (2011a) has identified the need to develop new tools for risk management. In addition, a questionnaire survey (Vinnem et al., 2010) carried out for PSAN as a supervisory activity in 2009 revealed the need for the development of such tools, as it showed that the current risk analysis studies employed by the sector were not utilised "as input to day-to-day decisions on installations/plants about minor modifications, maintenance and intervention activities" (Vinnem and Haugen, 2012, p. 4).

1.2 Problem formulation

The main purpose of this master's thesis is to explore and describe how barrier management can be directly linked to operational control of major accident risk. The report will examine how the platform manager can use information on the state of the safety barriers as a risk control tool. The report will explore and describe the premises for a new risk control tool including, but not limited to, a description of the type of information that goes into the risk control tool, the sources of such information, and the output the tool provides. Furthermore, the report will indentify how decision-making criteria can be set for the activities that are not permitted based on such information. The report will present the most important decisions the management of the platform makes where the information on barrier condition is of importance, as well as how risk considerations come into these decisions. Furthermore, the report will discuss how the total risk on the platform can be considered against acceptance criteria for risk.

1.3 Objectives

The main objectives of the master's thesis are:

1. Literature study - What does the concepts of risk, operational safety, safety barriers, risk management, barrier management and high reliability organisations entail? Identify and briefly summarise the concepts. How are safety barriers used in operational decision-making, and what important regulatory requirements, stipulated by PSAN, should be addressed regarding barrier management and a new risk control tool?

2. What are the premises for a new tool?
    - What is the purpose of the new tool?
    - What are the expectations to the new tool?
    - What are the requirements to the new tool?
    - Who are the user(s) of the new tool?
    - In what situations should the tool provide support?
    - What are the most important decisions the management of the platform makes where the information on barrier condition is of importance, and how do risk considerations come into these decisions?
    - How should information be communicated?
    - What should be presented to the user(s)?
    - What type of information goes into the new risk control tool, and what are the sources of such information?

- On which safety barriers should status be communicated on, and what properties are important to monitor and subsequently convey status on through the tool?

3. What are the important barriers, risk influencing factors and indicators that have to be considered for the new risk control tool? Furthermore, how can the total risk of the platform be considered against acceptance criteria for risk? Give examples of company specific methods, processes and tools, in relation to the topic of the thesis.

4. How can decision-making support be provided related to planning of activities on the installation, including decision-making criteria for the activities that are not permitted based on, amongst other, information on the state of the safety barriers? Furthermore, give an example utilising the presented decision-support.

1.4 Limitations and scope

The following master's thesis has the objective of examining and describing a new risk control tool, and is developed in cooperation with Det Norske Veritas (DNV). The possibilities of doing this are researched within existing methods, measures and models, as well as other methods. The development of a complete tool is, however, not within the scope of this master's thesis.

The thesis is based on regulations and standards valid to the offshore oil and gas industry on the NCS, and is specific to this industry. Moreover, the scope of the thesis is focused on major accident risk.

The risk control tool described in the following thesis is a tool to be used during planning of activities offshore by onshore and offshore personnel, and is furthermore limited to be used before (and not after) initiating or accidental events. The risk control tool shall convey decision support to the user(s), when the user(s) are to decide whether an activity can or cannot be performed. Moreover, the decision-making and support presented in this master's thesis is focused on decision-making and support on the installation. The risk control tool in question is supposed to be a “simple to use” tool for everyday use, i.e. not a time-consuming risk analysis tool. However, this does not exclude the fact that such a tool can have extensive calculation capabilities and advanced software built into it allowing for e.g. risk assessments. Furthermore, the "decision-making and support related to planning of activities on the installation" outlined in this master's thesis assumes that barrier status is available and up to date.

The following thesis does not cover in detail how barriers are established, as this was extensively researched in the project thesis by Madsen (2012) the autumn of 2012. In addition, the following thesis does not include visual design of the risk control tool.

1.5 Approach

The following have, amongst other, been undertaken to answer the problem formulation of this master's thesis:

- Visit to DNV Høvik including meeting with Helle Piene Fløtaker and Børre Johan Paaske on the 28th to the 30th of January 2013.
- Attended seminar on Safety and Asset Risk Management at DNV´s office in Trondheim, Norway on the 5th of February 2013.
- Attended video meeting between the onshore management and the management offshore on Åsgard B and C at Statoil's office in Stjørdal, Norway on the 15th of February 2013.
- Phone meeting with Snorre Sklet on the 27th of February 2013.
- Meeting with Snorre Sklet at Statoil's office in Trondheim, Norway on the 8th of March 2013.
- Meeting with and interview of Jan Morten Ertsaas, former platform manager of Statfjord C, on 11th of March 2013 at the office of Safetec Nordic AS in Trondheim, Norway.
- Attended seminar on Management and Major Accident Risk at PSAN's office in Stavanger, Norway on the 21st of March 2013.
- Interview of Øystein Michelsen, Executive vice president, Development and production Norway, Statoil, during a taxi ride on the 21st of March 2013 between PSAN´s office in Stavanger, Norway and Stavanger Airport, Sola, Norway.

- Meeting with and interview of Ola Olsvik, former platform manager of Åsgard A and Statfjord A, on 5th of April 2013 at Statoil's office in Trondheim, Norway. This meeting was partly conducted to verify the statements from Jan Morten Ertsaas.
- Meetings with supervisors, Jan Erik Vinnem and Helle Piene Fløtaker, on a regular basis throughout the spring of 2013.
- A literature study on the topics of amongst other; risk, operational safety, safety barriers, risk management, barrier management, high reliability organisations, operational decision-making, risk influencing factors and indicators.
- An exploration and review of the important premises for a new risk control tool including, but not limited to, it's input and output, and how it can provide decision-making support.
- A literature study and review of how the total risk of the platform can be considered against acceptance criteria for risk during the operational phase.
- A review of existing measures, methods and tools.
- Development of decision-making support related to planning of activities on the installation, including decision-making criteria for the activities that are not permitted based on, amongst other, information on the state of the safety barriers.

1.6 Structure of report

The remaining part of the thesis is structured as follows:

Chapter 2: An introduction to the concepts of risk, operational safety, safety barriers, risk management, barrier management and high reliability organisations, based on a literature study on the topics. In addition, the chapter identifies how safety barriers are used in operational decision-making and presents important regulatory requirements stipulated by PSAN.

Chapter 3: Stating the premises for a new risk control tool including, but not limited to, its purpose, users, expectations, requirements, situations of use and how information should be communicated. In addition, decisions in need of support and how risk considerations come into such decisions are presented. Furthermore, the chapter describes the type of information that goes into the new risk control tool, the sources of such information, and the output the risk control tool provides. Moreover, the chapter reviews which safety barriers status should be communicated on, and what properties of safety barriers that are important to monitor and subsequently convey status on through the tool.

Chapter 4: A presentation of important barriers, risk influencing factors and indicators for offshore oil and gas installations that have to be considered for the new risk control tool. Moreover, the chapter gives examples of company specific methods, processes and tools, in addition to a method for considering the total risk of the platform against acceptance criteria for risk.

Chapter 5: The chapter presents how decision-making support can be provided related to planning of activities on the installation, including decision-making criteria for the activities that are not permitted based on, amongst other, information on the state of the safety barriers. In addition, the chapter presents an example utilising the presented decision-support.

Chapter 6: The chapter contains a discussion of the results of this thesis in general and in relation to the topic of the master's thesis.

Chapter 7: Conclusion of the master's thesis, as well as recommendations for further work.

Chapter 8: List of references used in the master's thesis.

1.7 Intended audience

This document is intended for the following audience:

a) Jan Erik Vinnem, PhD, Department of Marine Technology, Norwegian University of Science and Technology;
b) Helle Piene Fløtaker and Børre Johan Paaske, Det Norske Veritas;
c) Those responsible for ensuring safe operations within their organisation; and
d) Those working with, and/or improving, operational safety for platforms on the Norwegian Continental Shelf.

1.8 Abbreviations

AHRQ	Agency for Healthcare Research and Quality
ALARP	As Low As Reasonably Practicable
ANSI	American National Standards Institute
ASV	Annulus Safety Valve
BBD	Barrier Block Diagram
BD	Blow Down
BDV	Blowdown Valve
BOP	Blowout Preventer
BORA	Barrier and Operational Risk Analysis
BP	British Petroleum
CCR	Central Control Room
CEO	Chief Executive Officer
CM	Corrective Maintenance, or Condition Monitoring
DFUs	Defined situations of hazardous and accidents
DHSV	Down Hole Safety Valve
DNV	Det Norske Veritas
ESD	Emergency Shut Down
ESDV	Emergency Shut Down Valve
ESREL	Annual conference of the European Safety and Reliability Association
FAR	Fatal Accident Rate
HC	Hydrocarbon
HIRA	Hazard Identification and Risk Assessment
HMI	Human – Machine Interface
HRO	High Reliability Organisation
HSE	Health, Safety and Environment
HVAC	Heating, Ventilation and Air Conditioning
IE	Initiating Event
IEC	International Electrotechnical Commission
IMO	International Maritime Organization
IMT	Department of Marine Technology
IPL	Independent Protection Layer
ISC	Ignition Source Control

ISO	the International Organization for Standardization
KPI	Key Performance Indicator
LOPC	Loss Of Primary Containment
MOC	Management Of Change
MWE	Management and Workforce Engagement,
NAT	Normal Accident Theory
NCS	Norwegian Continental Shelf
NORSOK	The Competitive Position of the Norwegian Continental Shelf
NTNU	Norwegian University of Science and Technology
OGP	International Association of Oil & Gas Producers
OTS	Operational Conditions Safety
P&ID	Piping and Instrument Diagram
PA	Public Address
PFP	Passive Fire Protection
PHA	Process Hazard Analysis
PLL	Potential Loss of Life
PM	Preventive Maintenance
PR	Performance Requirement
PS	Performance Standard
PSAN	Petroleum Safety Authority [Norway]
PSV	Pressure Safety Valves
PTW	Permit To Work
QRA	Quantitative Risk Analysis
RAC	Risk Acceptance Criteria
RID	Risk Influencing Diagram
RIF	Risk Influencing Factor
RNNP	Risk Level in the Norwegian Petroleum Activity
RWE Dea	Rheinisch-Westfälisches Elektrizitätswerk Deutsche Erdöl-Aktiengesellschaft
S&S	Start-ups and Shutdowns
SIA	Safety Instrumentation and Alarms
SJA	Safe Job Analysis
TIMP	Technical Integrity Management Portal
TTS	Technical Conditions Safety
WP	Work Permit

2 INTRODUCING RISK- AND BARRIER MANAGEMENT

2.1 Introduction

A certain amount of risk is inherent in operations performed in the petroleum industry, as the industry work with highly flammable substances. This chapter presents a brief literature study on the topics of, amongst other, risk, safety barriers, operational safety, risk management, barrier management, high reliability organisations, and the use of safety barriers in decision-making. In addition, the chapter presents regulations that are found to be particularly important in relation to *barrier management* as well as concerning a new *risk control tool*.

2.2 What is risk?

Rausand (2011, p. 603) defines the term *risk* as "The chance of something happening that will have an impact upon objectives", while the ISO 31000 (2009, p. 1) standard defines the term as the "effect of uncertainty on objectives". Risk is therefore about something that might occur, rather than something that has occurred.

There are more than one perspective on risk, the most common in the offshore petroleum industry being the expected value. Vinnem (2007), amongst other, expresses the expected value as:

$$R = \sum (p_i \cdot C_i)$$

where p is the probability of occurrence of an accident, while C is the consequences of the possible accident. As can be seen from the formula above, this perspective does not account for uncertainties. Aven (2008) includes uncertainty U in what can be referred to as the (A,C,U) perspective. Uncertainty U is, in this context, the uncertainty about "observable quantities expressing states of the real world" (Vinnem and Haugen, 2012, p. 5). Aven (2008) expresses the (A,C,U) perspective as follows:

$$R = (A, C, U)$$

where A is the event, C is the consequence of the event, and U is the uncertainty. The uncertainty U is furthermore based on a background knowledge K, covering amongst other "the phenomena in question (…), historical system performance data, management strategies" (Vinnem and Haugen, 2012, p. 5) and other assumptions.

2.2.1 Occupational risk vs. major accident risk

The NORSOK Z-013 (2010, p. 12) standard defines, in close resemblance to the definition given by PSAN (2012a), a major accident as:

> *Major accident:* acute occurrence of an event such as a major emission, fire, or explosion, which immediately or delayed, leads to serious consequences to human health and/or fatalities and/or environmental damage and/or larger economical losses.

Two fairly recent major accidents involving British Petroleum (BP), the Macondo disaster in April 2010 (Deepwater Horizon Study Group, 2011) and the Texas City refinery explosion and fire in March 2005 (U.S. Chemical Safety and Hazard Investigation Board, 2007), has shown signs of misconception of how to address major accident risk. In both cases, status of occupational accidents was used as status for major accident risk (Vinnem, 2013a). Fløtaker (2013a) explains that occupational accidents have a fairly high frequency in relation to major accidents. Occupational accidents are therefore easier to relate to and focus on. On the other hand, major accidents are fewer in numbers so the idea of a major accident seems very distant. The importance of distinguishing between occupational risk and major accident risk is illustrated in Figure 2.1. The numbers displayed in the figure are not absolute as there are fewer major accidents than there are occupational accidents in reality.

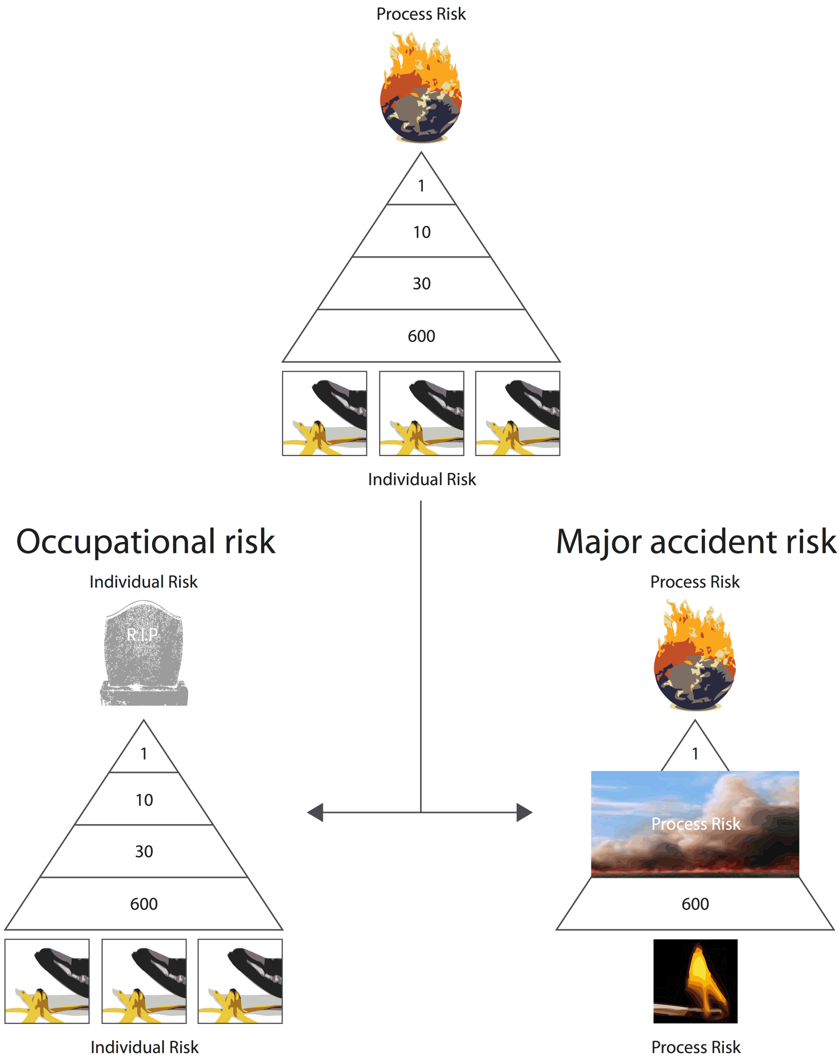

Figure 2.1: Distinguish between occupational risk and major accident risk, based on Våge (2012)

DNV has presented the following distinction between the key characteristics of Process Safety Risk and Occupational Safety Risk (Fløtaker, 2011):

Occupational Safety Risk	**Process Safety Risk**
Linear chain of events Simple causation relationship Usually limited consequences	Multi-linear chain of events Complex causation relationship Potential catastrophic consequences Potential for escalation

Table 2.1: Key characteristics of risk, based on Fløtaker (2011)

Major accident risk is managed by barrier management, which is described in chapter 2.7.

2.3 The safety barrier concept and classification

There are many sources of danger on a platform that can cause serious harm to assets such as people, the environment and company property. These sources of danger, also known as hazards, have to be treated and dealt with to ensure continuous safe operations. The term *barrier* is frequently used to portray an obstacle that has to be overcome for something to happen. In an anecdote, PSAN (2011b) describes a barrier as a fence that restricts access from either side. The online dictionary from Merriam-Webster defines the term *barrier* as (Merriam-Webster, 2013a):

1. a : something material that blocks or is intended to block passage
   b : a natural formation or structure that prevents or hinders movement or action
2. something immaterial that impedes or separates: obstacle

Gibson (1961) and Haddon (1970, 1980) are renowned for their work within the field, and are frequently recognized for the introduction of the term *safety barrier* as well as the accident model known as the energy-barrier model, where a vulnerable target is protected from a hazard by a barrier. The Energy Model is shown in Figure 2.2.

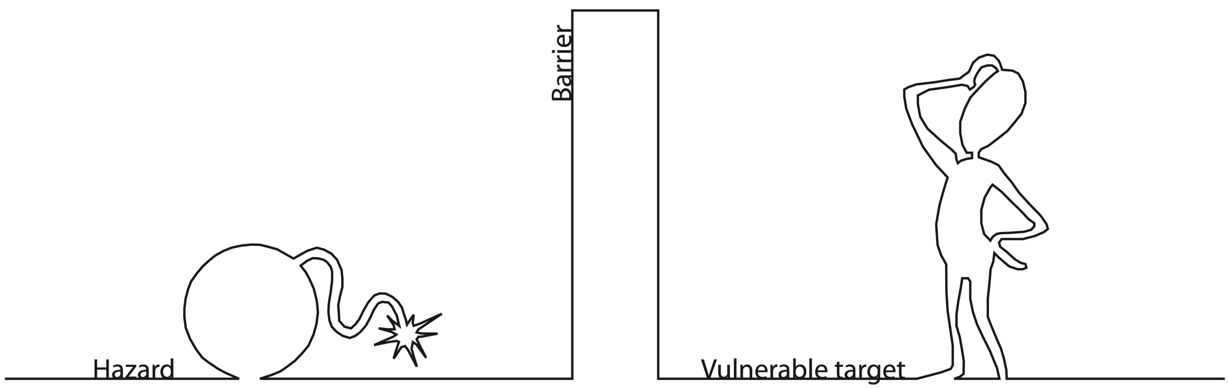

Figure 2.2: The Energy Model, based on Haddon (1980)

The NORSOK Z-013 (2010, p. 14) standard defines a *safety barrier* as:

> *Safety barrier*: Physical or non-physical means planned to prevent, control, or mitigate undesired events or accidents.

Furthermore, PSAN (2012b) describes a *safety barrier* in the oil and gas industry as a barrier that:

a. reduce the probability of failures and hazard and accident situations developing
b. limit possible harm and disadvantages

The description by PSAN (2012b) is, in its essence, the elements in a common risk model known as the Bow-Tie Model, shown in Figure 2.3.

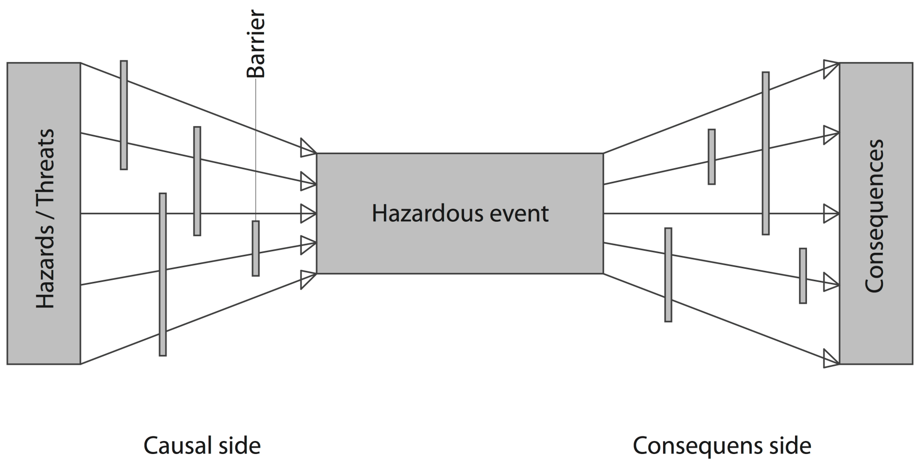

Figure 2.3: The Bow-Tie Model, based on Rausand (2011)

Rausand (2011) states that the Bow-Tie Model describes the relationship between a hazardous event and its causes and consequences. Hollnagel (2008) states that safety can be achieved in three ways using this model:

- Elimination of hazards
- Preventing initiating events
- Mitigating the consequences

Hollnagel (2008, p. 225) explains further that preventing initiating events is the "hindering of preconditions or initiating factors from triggering or contributing to an accident". On the other hand, mitigating the consequences is the action to reduce or minimize the severity or the loss following a hazardous event.

Sklet (2006) provides a detailed study of how barriers can be defined and classified. His proposals for definitions are fairly similar to those proposed by PSAN (2011b), and those found in NORSOK Z-013 (2010), although PSAN (2011b) has proposed to use the term *barrier* instead of *barrier system*. The definitions provided by NORSOK Z-013 (2010, p. 8) are:

> Barrier *function:* function planned to prevent, control, or mitigate undesired or accidental events.
>
> Barrier *system:* system designed and implemented to perform one or more barrier function.
>
> Barrier *element:* physical, technical or operational component in a barrier system.

Based on his definitions, Sklet (2006) recommends the classification of safety barriers categorised by system, as shown in Figure 2.4.

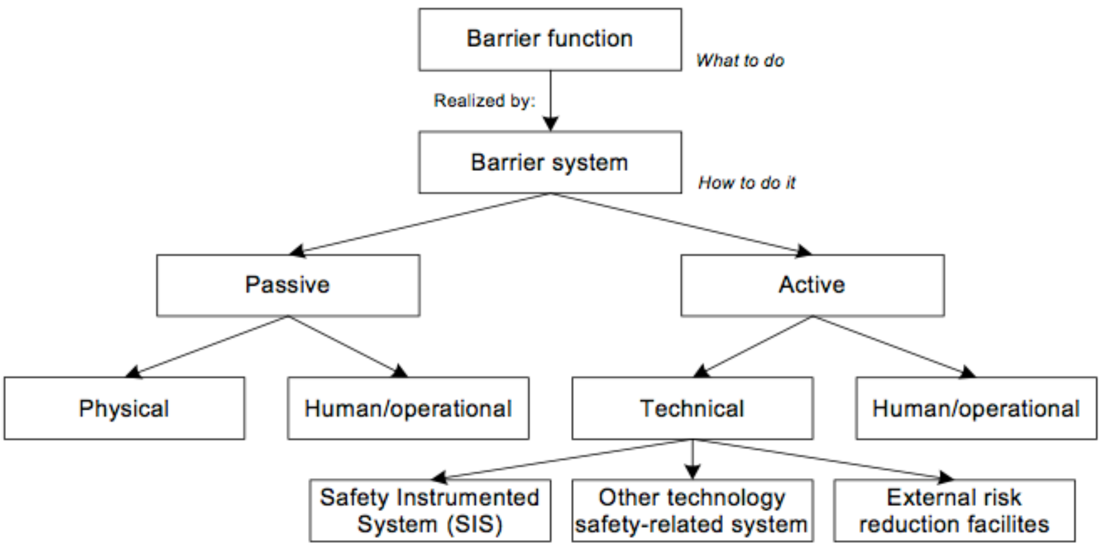

Figure 2.4: Classification of safety barriers, Sklet (2006)

Corneliussen, K. and Sklet, S. (2003) describe the difference between active and passive independent protection layers (IPL). Even though Corneliussen, K. and Sklet, S. (2003, p. 3) use different terminology, the difference between active and passive barrier elements can be said to be that a passive barrier element "is not required to take an action in order to achieve its function in reducing risk", whilst active barrier elements "are required to move from one state to another in response to a change".

2.4 Operational safety

Hollnagel (2008, p. 221) states that safety and risk are linked due to the fact that "Safety is (…) defined as the absence of unwanted events, which essentially means as the absence of risk". The complete elimination of risk requires that the source of risk can be completely removed from the system, without the system loosing its function (Hollnagel, 2008). This is often not a viable option for the petroleum industry in general, which for instance works with highly flammable substances. Hollnagel (2008, p. 221) goes on and states that a "higher level of safety is equivalent to a lower occurrence of" unwanted events.

According to DNV (2012a), most accidents today do not primarily result from deficient design, but from "inadequate operational safety not sufficiently addressing specific threats inherent in the operation". Operational safety is, in this context, "defined" by DNV (2012a) as:

> *Operational safety*: the collection of safety services that supports operational managers achieve and maintain the high levels of safety and mechanical integrity required by regulation and by their own safety and risk processes.

During The Barrier and Operational Risk Analysis Project (Vinnem et al., 2007) between 2003 and 2006, where a quantitative risk analysis (QRA) approach for modelling the total risk of an accident scenario was developed, a barrier block diagram (BBD) illustrating how the state of operation is affected by the state of the barrier system was established. This BBD is shown in Figure 2.5.

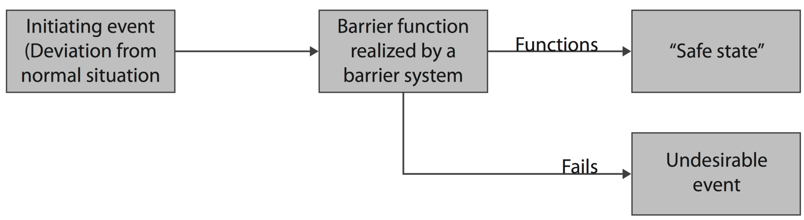

Figure 2.5: Illustration of a barrier block diagram, based on Vinnem et al. (2007)

It should be noted that this BBD illustrates the event sequence after an initiating event.

2.5 Important regulatory requirements

Platforms on the NCS are exposed to function based regulations, and risk analysed operations. There are many rules, regulations and standards addressing the matter of safe operations and describing the requirements to systems and solutions that are put in place to prevent accidents. These also apply to platforms standing on the NCS. The following table is based on excerptions of regulations from PSAN (2011c, 2012b, 2012c, 2012d) that are considered to be of special importance in this context. The regulations have been chosen on a basis of being particularly important in relation to barrier management as well as concerning a new risk control tool.

Regulation	Paragraph	Main concerns in paragraph
The Management Regulations	4	**Risk reduction** • There shall be selected technical, operational and organisational solutions to reduce risk. • The solutions shall reduce the probability of occurrence of harm, errors and hazard and accident situations. • Barriers shall be established. • Barriers that have the greatest risk-reducing effect shall be chosen based on evaluation. • Collective protective measures shall be preferred over protective measures aimed at individuals.
	5	**Barriers** • There shall be established barriers to reduce the probability of failures and hazard and accident situations developing, and limit possible harm and disadvantages. • Where it is necessary to have multiple barriers, there shall be sufficient independence between the barriers. • There shall be stipulated strategies and principles that form the basis for design, use and maintenance of barriers. • A barrier's function shall be safeguarded throughout the facilitiy's life. • It shall be known which barriers are established and the functions they must fulfil. • It shall be known what performance requirements have been defined for the individual barrier to be effective. • It shall be known which barriers are not functioning or are impaired. • Necessary measures to correct or compensate for missing or impaired barriers shall be implemented.
	6	**Management of health, safety and the environment** • It shall be ensured that the management of health, safety and the environment comprises the activities, resources, processes and organisation necessary to ensure prudent activities and continuous improvement. • Responsibility and authority shall be unambiguously defined and coordinated at all times. • The necessary governing documents shall be prepared, and the necessary reporting lines shall be established.

Regulation	Paragraph	Main concerns in paragraph
	10	**Measurement parameters and indicators** • Measurement parameters shall be established to monitor factors of significance to health, safety and the environment, including the degree of achievement. • There shall be established indicators to monitor changes and trends in the major accident risk and environmental risk.
The Framework Regulations	11	**Risk reduction principles** • Harm or danger of harm to people, the environment or material assets shall be prevented or limited in accordance with the health, safety and environment legislation, including internal requirements and acceptance criteria that are of significance for complying with requirements in this legislation. In addition, the risk shall be further reduced to the extent possible. • If there is insufficient knowledge concerning the effects that the use of technical, operational or organisational solutions can have on health, safety or the environment, solutions that will reduce this uncertainty, shall be chosen. • There shall be carried out assessments during all phases of the petroleum activities.
The Activities Regulations	47	**Maintenance programme** • The effectiveness of maintenance should be systematically evaluated on the basis of recorded data for performance and technical condition of facilities or parts thereof (Fløtaker, 2011). • The evaluation will be used for continuous improvement of the maintenance program (Fløtaker, 2011).
The Facilities Regulations	21	**Human-machine interface and information presentation** • Monitor-based equipment and other technical equipment for monitoring, controlling and operating machines, installations or production processes, shall be designed to reduce the risk of mistakes that can have an impact on safety. • Information transmitters and operating devices shall be designed, placed and grouped to allow for simple and quick receipt of necessary information and implementation of necessary actions. The presented information shall be correct and easy to understand. • Information systems shall be dimensioned for both normal and critical situations. • In the event of incidents, nonconformities or faults in systems of significance to safety, alarms shall be activated that clearly differ from other information. The alarms shall be given such that they can be understood and handled in the time required for safe operation of equipment, installations and processes.

Table 2.2: Regulatory requirements, based on excerptions from PSAN (2011c, 2012b, 2012c, 2012d)

2.6 Risk management

The ISO 31000 (2009) standard provides principles, framework and processes for risk management, and is a standard used by the petroleum industry. Thus, the standard provides principles and guidelines to help manage risk. Rausand (2011, p. 604) defines *risk management* as:

> *Risk management*: A continuous management process with the objective to identify, analyze, and assess potential hazards in a system or related to an activity, and to identify and introduce risk control measures to eliminate or reduce potential harm.

Figure 2.6 shows the process of risk management, which is viable both in a design phase and in a planning phase for an operation, as stipulated by ISO 31000 (2009).

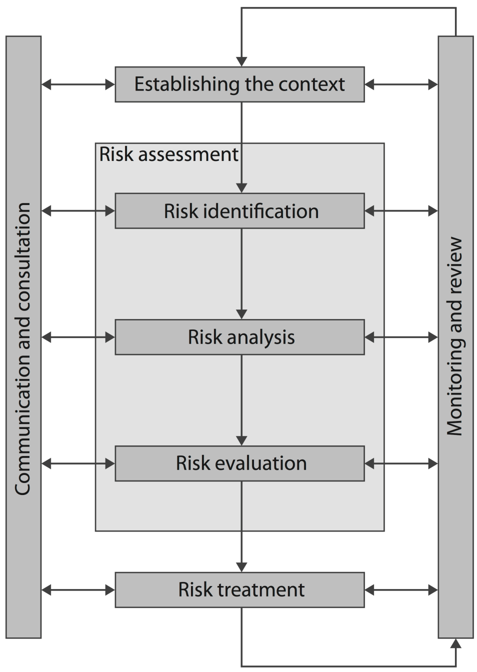

Figure 2.6: Process of risk management, based on ISO 31000 (2009)

The process of risk management, as described in ISO 31000 (2009), starts out with given situations, assumptions and context (conditions) as a basis for establishing the risk picture through the process of risk assessment. This is performed to create an overview of the unwanted events that can occur, as well as their causes and consequences. In addition, conditions that are influencing, as well as uncertainty, should be described. Barriers, defined as risk control options in ISO 31000 (2009), are then implemented to reduce the risk to an acceptable level using risk acceptance criteria (RAC) through the process of risk treatment. The As Low As Reasonably Practicable (ALARP) principle being one of the most commonly used (Rausand, 2009). Barriers, that have been implemented, have to be monitored to manage risk over time (ISO 31000, 2009). In addition, it should be confirmed that the facility is run in accordance with the context.

The planning phase as such, including establishment of the context and with it the risk criteria, risk assessment, risk treatment and plan, and communication and consultation, was extensively researched and documented in the project thesis *Operational Safety through Barrier Control for Platforms on the Norwegian Continental Shelf* of autumn 2012 (Madsen, 2012). It has therefore been found more useful to describe further in detail the necessary documentation / results of the planning phase, see chapter 2.7.2, in this master's thesis, as this serves as a basis for what is to be performed / monitored during the operational phase[1].

2.7 Barrier management

According to Faret (2010), investigations after serious incidents and near accidents have shown that the breach of barriers often is the reason that what should not have happened, happened. Figure 2.7, the Swiss Cheese Model, illustrates how breach of barriers can lead to a major accident.

The process of barrier management includes the establishment of barriers and the activities needed to maintain the barriers' function throughout the facility's lifetime (PSAN, 2013). Thus, barrier management includes the processes, systems, solutions and measures needed to ensure operational safety through sufficient risk reduction (PSAN, 2013).

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[1] This can be justified with the fact that the tool described in this thesis, of which is to be used by the platform manager and the onshore management, is not supposed to be a heavy risk analysis method as what was described in the project thesis, but rather a "easy to use" day-to-day tool which utilises the outcome of such an extensive analysis as a basis together with, amongst other, barrier status to provide risk-based decision support.

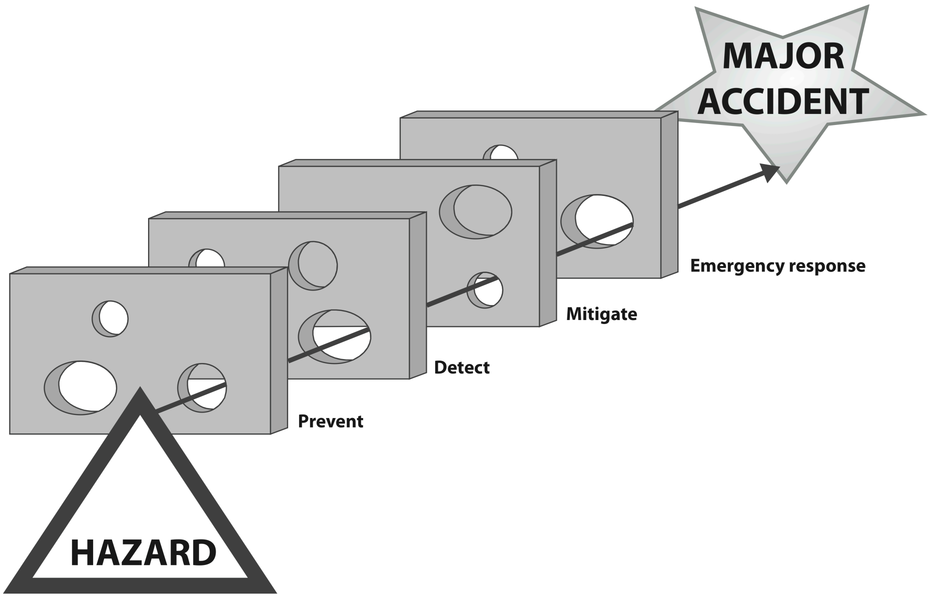

Figure 2.7: The Swiss Cheese Model, based on Reason (1990)

PSAN (2013) defines *barrier management* as coordinated activities to establish and maintain barriers so that they at all times maintain their function. Hence, major accident risk can be managed with barrier management.

2.7.1 Concepts of barrier management

The following subchapters, chapter 2.7.1.1 and 2.7.1.2, presents two methods for barrier management as presented by PSAN and DNV respectively.

2.7.1.1 PSAN

PSAN (2013) has developed a framework for barrier management, illustrated in Figure 2.8, by using the risk management framework stipulated by ISO 31000 (2009) as a baseline. As seen in Figure 2.8, the framework is formed as a control loop centred around *Good installation design and safe operation*. The loop starts out with the process of establishing the risk picture and the barriers and strategies needed, in a planning, design or building phase, as described earlier in chapter 2.6 and later on in chapter 2.7.2. This plan is formed as to ensure that the requirements of and to barriers are met during the whole lifecycle. Furthermore, the result of this process shall be implemented and carried out as well as surveyed in the operational phase to assure that barriers and strategies are functioning as required. Results from surveying should then be verified and assessed as to be able to implement measures of improvements if and where necessary, as to assure continuous *Good installation design and safe operation*.

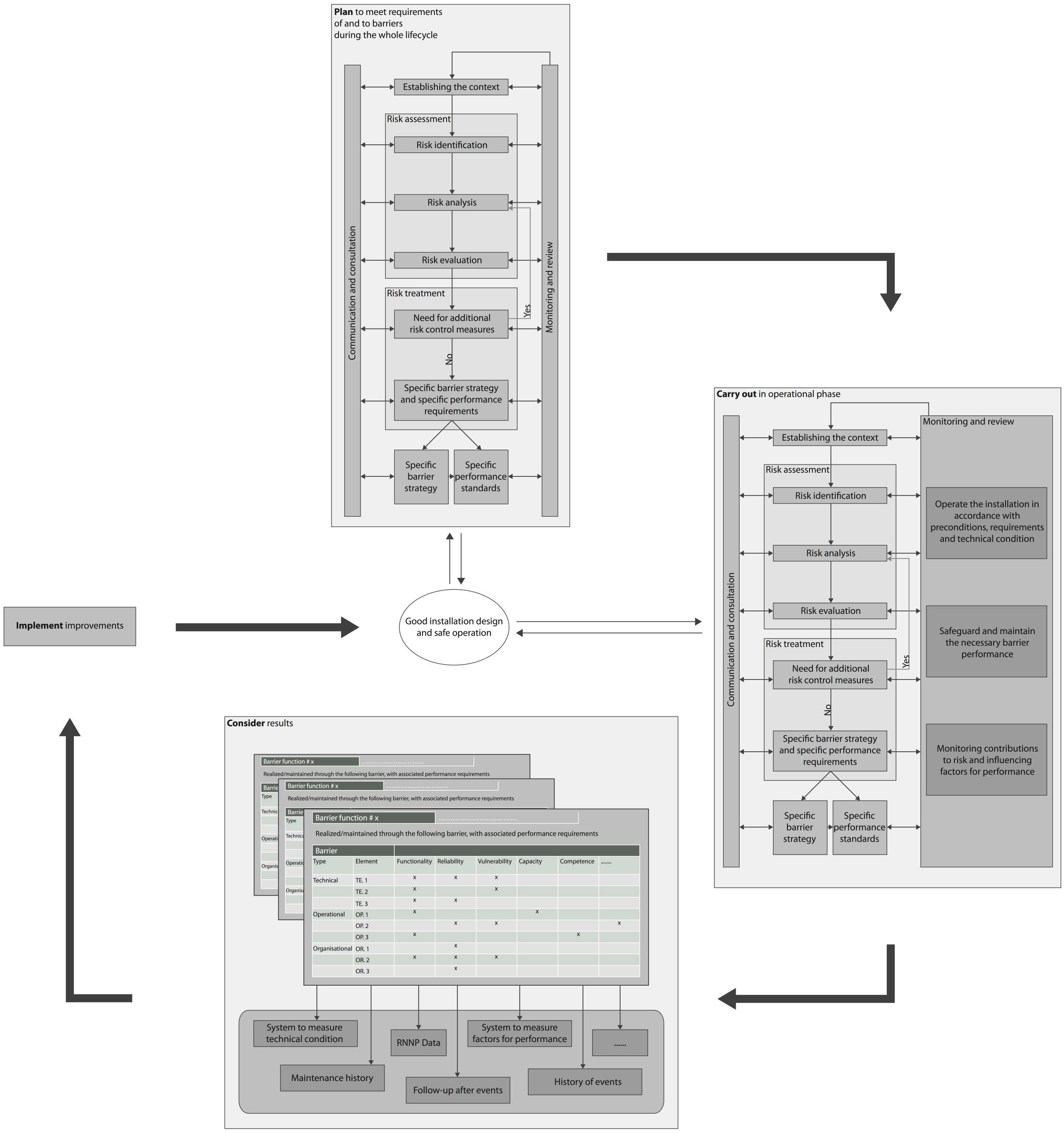

Figure 2.8: Framework for barrier management, based on PSAN (2013)

The first two parts of the control loop, *Plan* and *Carry out in operational phase*, in addition to a simplified framework for barrier management, can be found enlarged in Appendix A – Framework and parts of the process of barrier management. The third part, *verification of performance*, is presented later on in chapter 2.7.3.

2.7.1.2 DNV

In the aftermath of the Macondo accident, as well as due to PSAN`s focus on risk and barrier management, DNV has also established a process for barrier management. This process is shown in Figure 2.9. The resemblance between this process and the process for barrier management proposed by PSAN (2013) are fairly similar. As can be seen from Figure 2.9, DNV has built the process using ISO 31000 (2009) and PSAN`s document (PSAN, 2011b), which when translated from Norwegian names "*Principles for barrier management in the petroleum activities*", as a baseline.

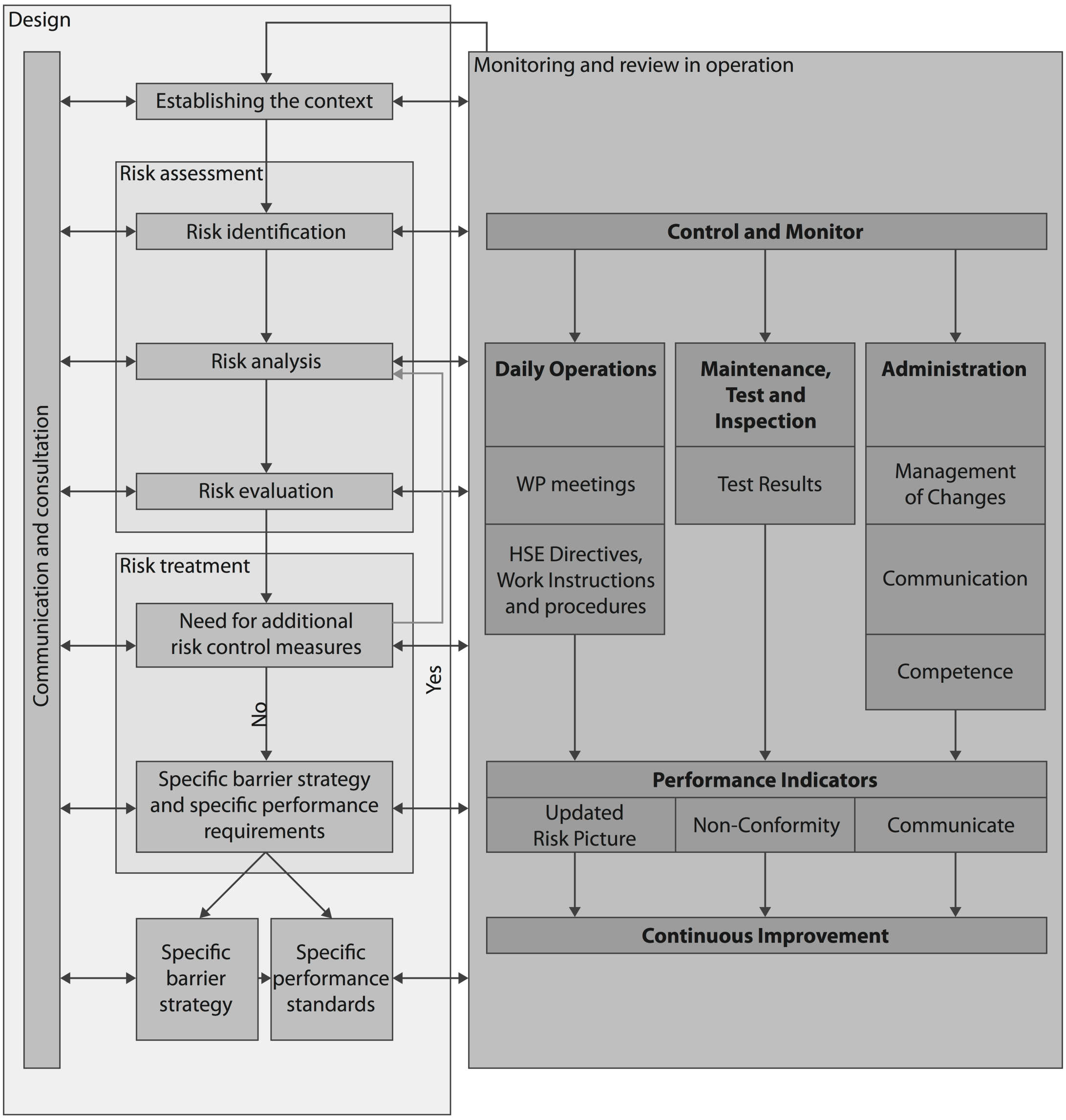

Figure 2.9: Barrier management, based on Våge (2012)

2.7.2 Outcome of the planning phase of barrier management

PSAN (2013) states that involved personnel have to have an understanding of why barriers are established (strategy), and the performance requirements (PRs) established for barrier elements to realise barrier functions. Moreover, involved personnel must have an understanding of how decisions, indirect or direct, affect the performance of barriers and/or the risk picture. ISO 31000 (2009) manages this with a *risk treatment plan*. The risk treatment plan documents the selected risk treatment options, and includes amongst other (ISO 31000, 2009):

- Motivation for selected treatment options
- Benefits of selected treatment options
- Those accountable for approving and implementing the plan
- Planned actions
- Resource requirements and contingencies
- Measures of performance and limits
- Requirements for reporting and monitoring
- Timing
- Schedule

PSAN (2013) has divided the risk treatment plan into two parts, establishing specific barrier strategy and establishing specified PRs in specific performance standards (PSs).

2.7.2.1 Specific barrier strategy

In accordance with Section 5 of the Management Regulations (PSAN, 2012b), there shall be stipulated "strategies and principles that form the basis for design, use and maintenance of barriers, so that the barriers' function is safeguarded". The barrier strategy is the result of a process describing what barrier functions and barriers shall be implemented based on the risk picture, and should (PSAN, 2013):

- be designed so that those involved can have a common understanding of the basis for the requirements of the various barriers, including:
    - phases, operations and activities for which the strategy is established.

  - the injury, hazard and accident situations that can occur in phases, operations and activities that the strategy is established for.
  - the barrier functions necessary to deal with these situations.
  - where one can find further information about PRs that apply to the individual barrier.
- be broken down to an appropriate level for the individual installations (e.g. area, system, equipment, "node").
- be broken down to an appropriate level to cover the various phases of the operation and activities it is applied to.
- be kept up to date.
- identify the role / task the different barrier functions have, whether it is to prevent hazard and accident situations occurring, or to limit damages / losses if they occur.
- identify key assumptions that are significant to the individual barrier function and each barrier element.
- demonstrate the transition between strategy and PRs established for the individual barrier. The strategy should provide information on how the different PRs for each barrier element and the individual barrier function are described.

2.7.2.2 Barrier performance criteria

The Swiss Cheese Model (Reason, 1990), shown in chapter 2.7, illustrates how breach of barriers can lead to a major accident. It is thus vital to know "what performance requirements have been defined for the individual barrier to be effective", as stipulated by Section 5 in the Management Regulations (PSAN, 2012b). PSAN (2011b) states that PRs are verifiable requirements for the risk control options` properties as to ensure that they are effective. According to PSAN (2013), PRs shall be established for technical, operational and organisational barrier elements. Furthermore, PSAN (2011b) proposes that the barrier PRs can, amongst other, be requirements of capacity, efficiency, reliability, availability, integrity, ability to resist loads and robustness.

Sklet (2006) recommends, after an extensive review of literature, the following performance criteria for safety barriers:

- Functionality/effectiveness: The ability to perform a specified function under given technical, environmental, and operational conditions
- Reliability/availability: The ability to perform a function with an actual functionality and response time while needed, or on demand
- Response time: The time from a deviation occurs that should have activated a safety barrier, to the fulfilment of the specified barrier function
- Robustness: The ability to resist given accident loads and function as specified during accident sequences
- Triggering event or condition: The event or condition that triggers the activation of a barrier

The trigging event is not a part of a barrier in itself, but "it is an important attribute in order to fully understand how a barrier may be activated" (Sklet, 2006, p. 504).

2.7.2.3 Barrier performance requirements in specific performance standards

PSAN (2013) states that it can be suitable to group the PRs into PSs. A PS is defined by NORSOK S-001 (2008, p. 12) as:

> the verifiable standard to which safety system elements are to perform. The objective of the specific safety performance standards is to add any supplemental safety requirements other than those specified by authority requirements and standards.

Furthermore the specific PSs shall be based upon the documents from the strategy and shall warrant that the safety barriers (NORSOK S-001, 2008, p. 12):

- are suitable and fully effective for the type hazards identified,
- have sufficient capacity for the duration of the hazard or the required time to provide evacuation of the installation,
- have sufficient availability to match the frequency of the initiating event,
- have adequate response time to fulfil its role,

- are suitable for all operating conditions.

There are a number of different PSs used by the industry, and they are often named in relation to the barriers/-system they are intended to describe. Some examples of PSs can be seen in Table 4.1 in chapter 4.2.1, which contains barriers/-systems found in NORSOK S-001 (2008). Furthermore, Våge (2012) states that PSs can be grouped into standards for functionality, integrity, survivability and management.

2.7.3 Barrier management in the operational phase

Barrier management is not "done" after the planning phase. Barriers have to be monitored during the operational phase, and their performances have to be reviewed and verified to manage risk over time (PSAN, 2013). According to PSAN (2011b), the process of monitoring and review is the most important part of ensuring a high-quality process of barrier management. This is due to the fact that accidents happen "when Barriers become Degraded" (Våge, 2012).

ISO 31000 (2009) states that monitoring and reviewing involves regular surveying of important parameters in the operational phase that influence the barriers and strategies, and is done to discover emerging risk and to ensure that the barriers and strategies are functioning and are as efficient as planned according to their requirements. Moreover, the result of monitoring and reviewing should also be used as input when reviewing the risk management process. Figure 2.10 shows some of the important parameters that influence the barriers and strategies that should be surveyed according to PSAN (2011b).

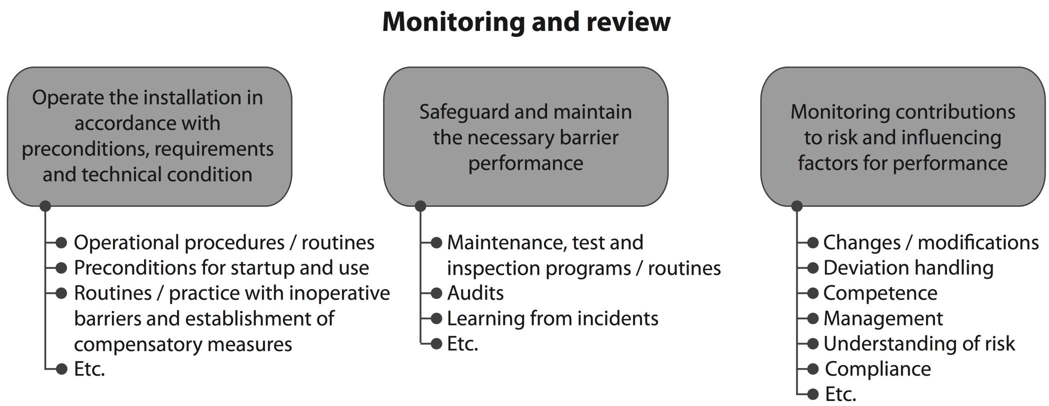

Figure 2.10: Monitoring and review, based on PSAN (2011b)

To verify that the barrier functions have the properties set forth by the PRs in the PSs, a process of verification has to be performed. Figure 2.11 (PSAN, 2011b) illustrates the process of verification of performance of barrier functions. It also presents some of the activities, measures and indicators that are utilized by the industry.

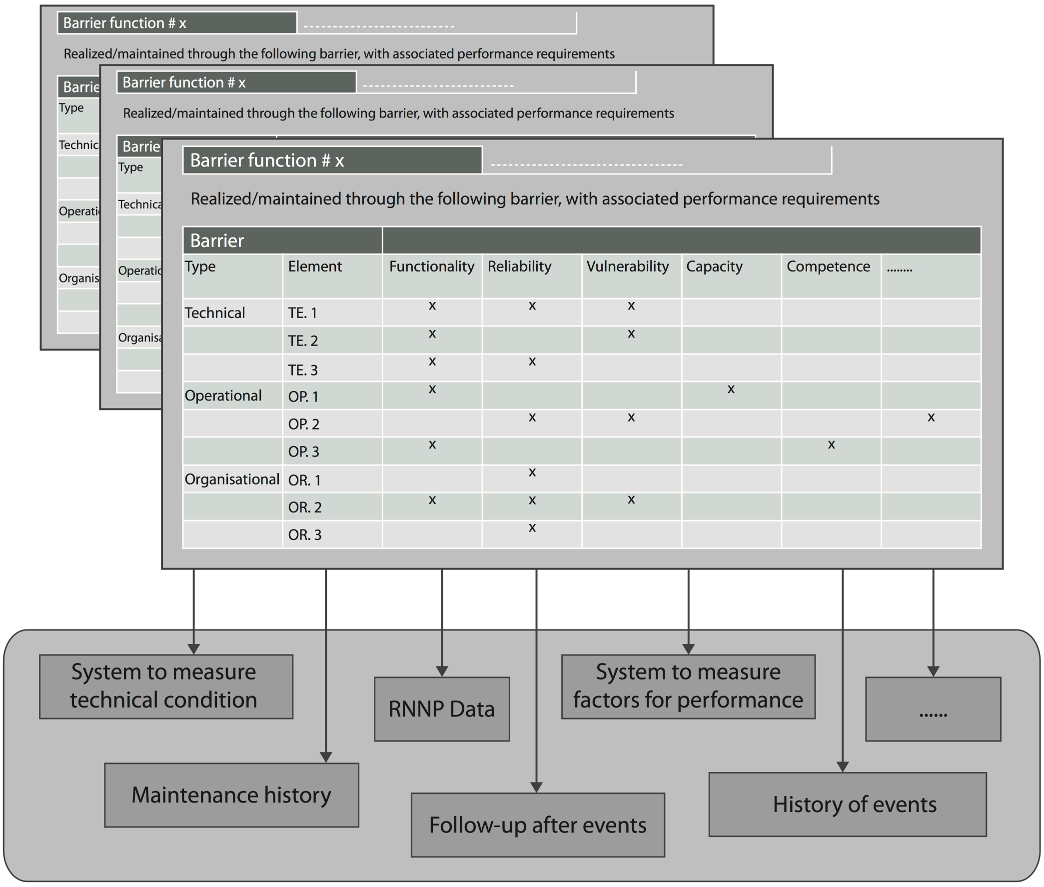

Figure 2.11: Verification of performance, based on PSAN (2011b)

2.8 High reliability organisations

There is much debate found in literature on how to define High Reliability Organisations (HROs). Rosness et al. (2010, p. 65) state that "the HRO perspective is founded on a research tradition that seeks to explain why so few serious accidents actually occur, especially in certain complex systems that operate under demanding circumstances".

Lekka (2011) has performed an extensive review of literature on the topic of HROs on behalf of the Health and Safety Executive. Lekka (2011, p. 5) found that HROs had been defined "in terms of an organisation's ability to sustain almost error-free performance over long time periods" by researchers at the University of California, Berkley. Due to an abundance of papers written on the topic of HROs, Lekka (2011, p. 18) established a mind map, shown in Figure 2.12, to summarise the associated processes and characteristics of HROs "in order to capture the common issues that emerged in the literature".

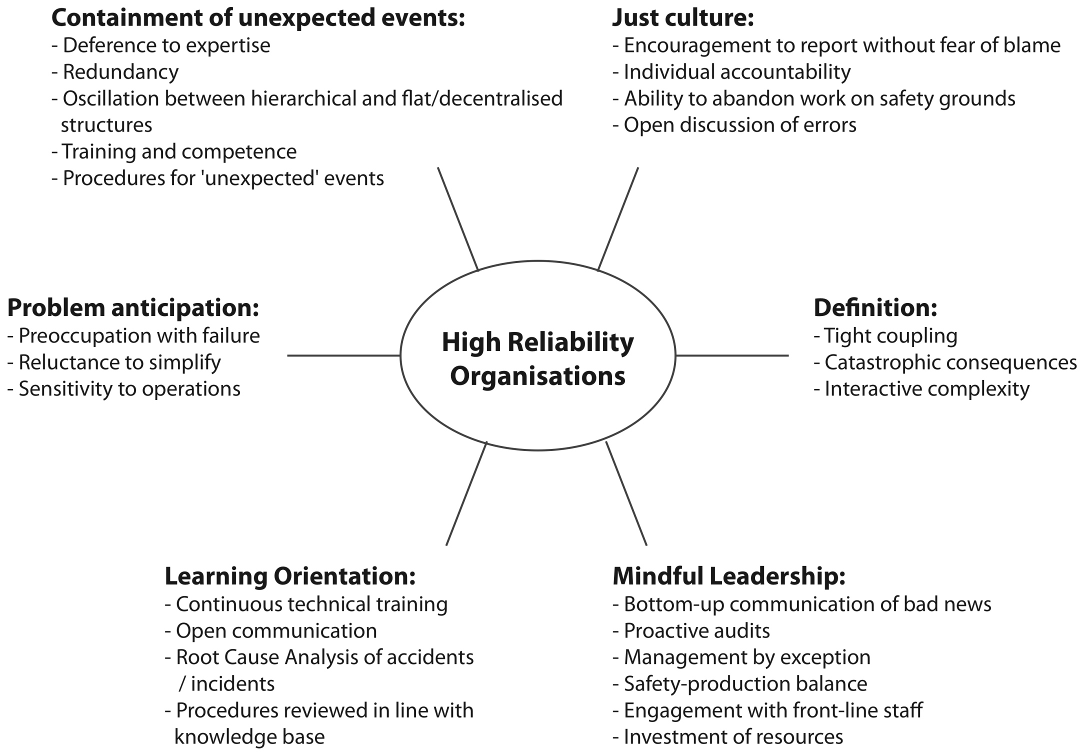

Figure 2.12: Mind map of HRO processes and characteristics, based on Lekka (2011)

Rosness et al. (2010) describe competing perspectives on safety with hazardous technologies. Table 2.3 shows a comparison between HRO and Normal Accident theory (NAT) as presented by Rosness et al. (2010, p. 63).

High Reliability Theory	Normal Accident Theory
Accidents can be prevented through good organisational design and management.	Accidents are inevitable in complex and tightly coupled systems.
Safety is the priority organizational objective.	Safety is one of a number of competing objectives.
Redundancy enhances safety: Duplication and overlap can make "reliable systems out of unreliable parts."	Redundancy often causes accidents: it increases interactive complexity and encourages risk-taking.
Decentralised decision-making is needed to permit prompt and flexible field-level responses to surprises.	Organizational contradiction: Decentralization is needed for complexity, but centralization is needed for tightly coupled systems.
A "culture of reliability" will enhance safety by encouraging uniform and appropriate responses by field-level operators.	A military model of intense discipline, socialisation, and isolation is incompatible with democratic values.
Continuous operations, training, and simulations can create and maintain high reliability organizations.	Organizations cannot train for unimagined, highly dangerous, or politically unpalatable operations.
Trial and error learning from accidents can be effective, and can be supplemented by anticipation and simulations.	Denial of responsibility, faulty reporting, and reconstruction of history cripples learning efforts.

Table 2.3: Competing perspectives on safety with hazardous technologies, based on Rosness et al. (2010)

The Agency for Healthcare Research and Quality (AHRQ, 2008) at the U.S. Department of Health & Human Services has stipulated five key concepts they believe are at the core of HROs:

- Sensitivity to operations: Preserving constant awareness by leaders and staff of the state of the systems and processes that affect patient care. This awareness is key to noting risks and preventing them.
- Reluctance to simplify: Simple processes are good, but simplistic explanations for why things work or fail are risky. Avoiding overly simple explanations of failure (unqualified staff, inadequate training, communication failure, etc.) is essential in order to understand the true reasons patients are placed at risk.
- Preoccupation with failure: When near-misses occur, these are viewed as evidence of systems that should be improved to reduce potential harm to patients. Rather than viewing near-misses as proof that the system has effective safeguards, they are viewed as symptomatic of areas in need of more attention.
- Deference to expertise: If leaders and supervisors are not willing to listen and respond to the insights of staff who know how processes really work and the risks patients really face, you will not have a culture in which high reliability is possible.

- Resilience: Leaders and staff need to be trained and prepared to know how to respond when system failures do occur.

Even though these concepts have been established for healthcare systems, the theory can be transferred to other complex system (also involving human beings).

2.9 Theory of decision-making and support

The online dictionary from Merriam-Webster defines the term *decision* as (Merriam-Webster, 2013b):

1. a : the act or process of deciding
   b : a determination arrived at after consideration
2. a report of a conclusion

Kaarstad et al. (2010, p. 27) define a decision as "the choice of one among a number of alternatives", and state that decision-making "refers to the whole process of making the choice". Kaarstad et al. (2010, p. 27) go on and state that decision-making include:

> assessing the problem, collecting and verifying information, identifying alternatives, anticipating consequences of decisions, making the choice using sound and logical judgment based on available information, informing others of decision and rationale, and evaluation decisions.

Thus, when a decision is to be made, the decision-maker relies on some sort of support to make an educated decision. Kaarstad et al. (2010) describe decision support as support to people making decisions. Decision support is not only computer based solutions, but also other tools and techniques helping the decision-maker. Two "disciplines (…) closely correspond to decision support", namely *Decision Theory* and *Decision System* (Kaarstad et al., 2010, p. 26). This is illustrated in Figure 2.13.

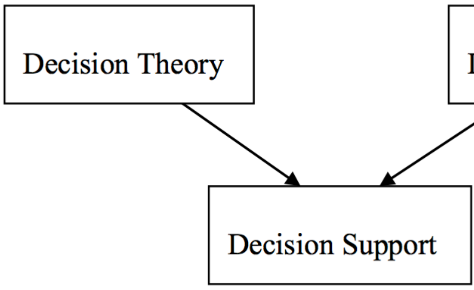

Figure 2.13: Decision support as impact by decision theory and decision system, Kaarstad et al. (2010)

Kaarstad et al. (2010, p. 26) goes on to state what is meant with Decision Theory and Decision Systems:

> *Decision Theory*: a broad discipline concerned with human decision making.
>
> *Decision System:* deals with computer-based programs and technologies intended to make routine decisions, and monitor and control processes.

Decision Theory is based on studies that have been performed for decades regarding the "human cognitive modes of comprehension, perception, representation and decision making" (Kaarstad et el., 2010, p. 27), and has been used to develop a number of decision support systems. *Decision Systems* are on the other hand computer-based solutions that support problem solving and decision-making (Karstad et al., 2010).

2.10 Use of safety barriers in decision-making

The management of an offshore platform have to balance safety objectives and production objectives on a regular basis. To achieve such balance the management must comply with predefined limits as described by regulations and company specific internal guidelines. Hayes (2012, p. 424) states that "Regulations and industry standards focus on defining and complying with operating limits of various kinds as the primary method of achieving the right balance". In the process industry, such limits can include (Hayes, 2012, p. 425):

- Maximum and/or minimum values of measurable system properties such as pressure, composition, or number of operators.

- Specific minimum requirements for equipment, e.g. must have one pump running and one on-line spare, or must not run without gas detection in place.

As can be seen, the limits are fixed boundaries that limit the operations as to ensure safety. By complying with such limits, the need for "judgments about safety and production priorities" (Hayes, 2012, p. 424) is removed in many cases. Hayes (2012) states further that to solely focus on complying with such limits underestimates what the professional judgement of the operational management or senior personnel can contribute to safety.

In a case study performed on cases from a process plant, a nuclear power station and an air navigation service, Hayes (2012, p. 431) discovered that operational managers do not use a framework of indentifying hazards and consideration of consequences and likelihood, but rather focus on the "barriers that had already been put in place". This "barrier approach" is found to be preferred over risk management as a decision-making frame, as it is linked "directly to the current state of the operational system" (Hayes, 2012, p. 431). Hayes (2012, p. 431) goes on and states that:

> For operational managers, ''safe'' means all safety barriers (or temporary alternatives) are in place. For organisations, ''safe'' means that the risk associated with the situation is tolerable.

Thus, operational managers rarely consider the specific probability of incidents or accidents on a daily basis, but rather see safety as an "active concept", where actions are focused on the following (Hayes, 2012, p. 431):

- Compliance with rules
- Ensuring sufficient integrity of the barriers that prevent a specific hazard from becoming a reality.

If barriers have been impaired or are non-functioning, Hayes (2012, p. 431) states that the operational manager would do one of the following:

- stop/limit/curtail activities to within the limits of the remaining barriers, or

- provide a temporary replacement barrier which might be increased monitoring by the operational team.

Building on these premises, an approach for decision-making during operation enabling the management to decide whether or not an activity can be performed based partly on information on the state of the safety barriers, is to be considered as suitable.

3 PREMISES FOR A NEW RISK CONTROL TOOL

3.1 Introduction

As a result of the Macondo disaster, PSAN (2011a) has identified the need to develop new tools for risk management. In addition, a questionnaire survey (Vinnem et al., 2010) carried out for PSAN as a supervisory activity in 2009 revealed the need for the development of such tools as it showed that the current risk analysis studies employed by the sector were not utilised "as input to day-to-day decisions on installations/plants about minor modifications, maintenance and intervention activities" (Vinnem and Haugen, 2012, p. 4).

There are a lot of factors to be considered in the process of "creating" a new tool. One has to consider its purpose, its users, the expectations to the tool, in what situations it shall be used, what information shall be communicated and what the data sources are, how the information shall be communicated or expressed to the users and so forth. Subsequent subchapters covers and review such aspects.

3.2 Situations and activities that influence risk

Risk is often classified as broadly acceptable, ALARP or unacceptable in a QRA (Rausand, 2011). In Norway, regulations only state the upper limit of risk through RAC (Vinnem, 2013c). However, DNV states that in the operational phase, risk can be seen as a base risk plus an additional risk, operational variable risk, that has to be controlled in order for continuous safe operation to be upheld (Fløtaker, 2013a). See illustration in Figure 3.1.

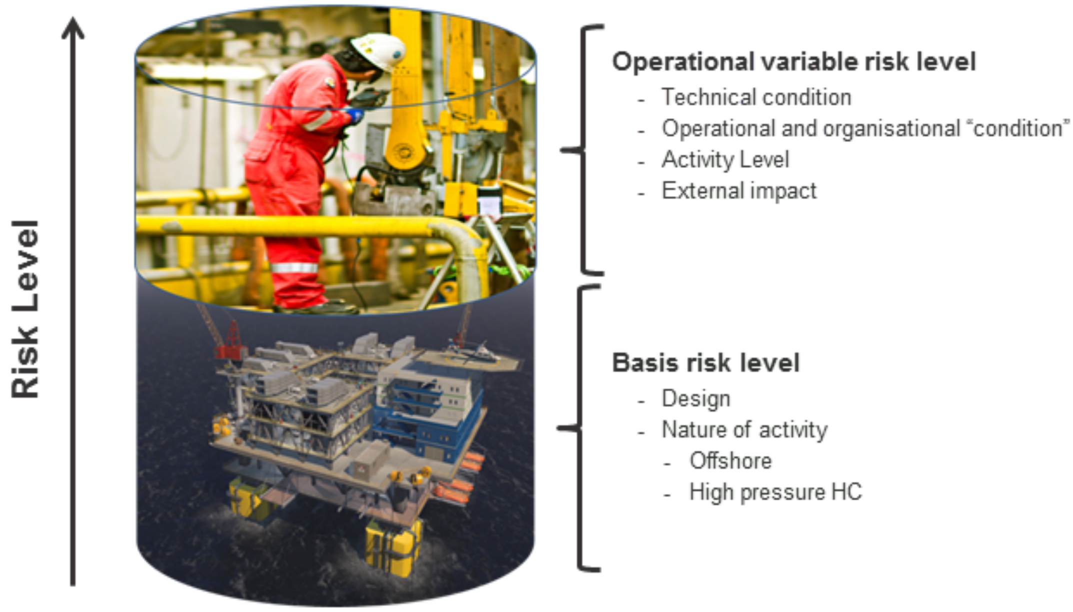

Figure 3.1: Perspective on risk, based on Fløtaker (2013c)

The risk to be controlled includes risk that comes from situations or activities that are associated with temporary increase of risk. The NORSOK Z-013 (2010) Risk and emergency preparedness assessment standard is utilised by the petroleum industry in Norway, and is applicable to platforms on the NCS. The standard describes "risk and emergency preparedness assessments for offshore and onshore facilities for production of oil and gas" (NORSOK Z-013, 2010, p. 7), and covers major accident risk. In this standard, the following situations and activities are stated to be associated with a temporary increase of risk (NORSOK Z-013, 2010):

- Drifting objects
- Work over open sea
- Unstable well in connection with well intervention
- "Hot" work
- Jacking up and down of jack-up installations
- Special operations
- Environmental conditions
- Construction related activities
- Significant increase of manning in construction periods
- Man over board

- Commissioning activities
- Marine activities
    - Flotel
    - Heavy lifting
    - Subsea installation
- Installation activities
- Turnarounds
- Combined construction and operational phases
- Maintenance shutdown periods
- Safety system temporarily out of operation
- Special lifting operations
- Drilling
- Other well activities
- Modification work

When addressing such situations and activities, the following aspects should be taken into consideration (NORSOK Z-013, 2010, p. 66):

- The duration of the period with increased risk,
- The peak level of risk during this operation,
- Whether the risk increase is local or global for the installation,
- Whether the risk increase affects the different personnel groups in the same way or differently.

3.3 Purpose of the new tool

As described in chapter 2.7, barrier management is linked to operational control of major accident risk. It can be stated that transient barrier performance causes transient levels of risk. In addition, activities like modifications, lifting and hot work causes change in risk level as described in chapter 3.2. As stated in chapter 2.5, barrier status is required to be known by the Management Regulations paragraph 5 and 10 from PSAN (2012b).

The purpose of the development of a new risk control tool is thus to provide decision support on a day-to-day basis by helping the decision-makers decide whether activities can or cannot be performed by utilise the information on the state of the safety barriers, other influencing factors and decision criteria. Other information that can be considered to help the decision-maker make educated decisions is also thought to be valuable to present through the tool. The user(s) of the tool can thus manage and obtain operational control of major accident risk on a day-to-day basis, by utilising information on the state of the safety barriers as a risk control tool. In addition to provide decision support, the tool can also be used to monitor factors that are presented through the tool.

3.4 Expectations to the new tool

When establishing the basis for a new tool, it is vital to know what is expected of the new tool. PSAN (2011a) issued a note in 2011 addressing the need for measures in the industry based on their follow-up of the Macondo accident. In addition, the tool has to satisfy the end user's expectations.

3.4.1 Petroleum Safety Authority Norway's expectations

In the aftermath of the Macondo accident, PSAN (2011a) performed a follow-up activity that included recommendations for the Norwegian petroleum activities. This follow-up activity identified three main focus areas; risk management, barrier management and organisation and management. PSAN (2011a) states that there is a need for research into and development of better tools for management of major accident risk. With tools PSAN (2011a, p. 2) means:

1. Methods, analysis, information, data, processes, etc. to analyse, evaluate and describe the risks in advance (in a planning phase).
2. Methods, analysis, information, data, management systems, processes, etc. to monitor, assess condition and the specific risk picture one face at any given time.
3. Methods, analysis, information, data, management systems, processes, etc. to identify and manage changes and the specific risk picture one face at any given time in a responsible manner.

Furthermore, the following aspects regarding tools that analyse, assess and manage risk should be addressed (PSAN, 2011a, p. 3):

- Strengths, weaknesses and limitations of the tools.

- The type of decision support the tool provides.
- The particular types of situations the tool should provide support.
- The decisions to which the tool should provide support.
- Information that would be relevant to better manage risk.

PSAN (2011a) states that barrier management should be an essential part of the framework for this work. In addition, the work should initially include those involved in everything from planning to execution of various activities / operations. It may also include decision support related to decisions made by managers at different levels.

3.4.2 User expectations

For the tool to be useful in the operational phase by its user(s) on a day-to-day basis, the generic user expectations shown in Table 3.1 have been established for the risk control tool. In addition to the generic user expectations, the table also expresses the author's opinion of why these expectations are of importance.

User expectation	**Why**
The tool should cause limited extra work.	They already have many tools they already use. Furthermore, they have much to do, and this tool shall help them.
Rely on, and take advantage of, information from other systems already in place.	There already exist systems and tools for registration / monitoring of e.g. barrier status (as required by regulations).
Not a new reporting tool.	There already exist systems and tools for registration / monitoring of e.g. barrier status (as required by regulations).
The tool presents a limited amount of information.	To get an overview of status, the tool should present the most important information.
The user should be able to "simulate" responses to activities.	A "simulation" function might be useful for instance when performing a safe job analysis, in addition to help them handle simultaneous activities.
Information on dispensation handling can be displayed.	When needed, information on dispensation handling should be available at the touch of a button. This is for instance important during handover.
Maintain user history	Management at different levels, onshore and/or offshore, should be able to view / review the use of the tool. User history should be maintained to document the use.

Table 3.1: Generic user expectations

3.5 General requirements to the tool

The tool shall, as stipulated in chapter 3.3, provide input to decision-makers in a decision-making processes. The general requirements of such a tool can thus be stipulated as:

- Rely on up to date and frequently updated information and input.
- Gather information from reliable data sources.
- Detailed and area specific barrier status known.
- Communicate decision-making criteria where needed.
- The tool should be relatively easy to use.

In addition, PSAN (2012c) requires that:

- Information systems shall be dimensioned for both normal and critical situations.[2]
- The tool shall be designed to reduce the risk of mistakes that can have an impact on safety.
- The presented information shall be correct and easy to understand.

Other aspects that are of importance include, but are not limited to:

- The tool will rely on indirect input from the staff aboard the platform. E.g. division managers' knowledge is of great importance.
- The tool should be able to present assumptions and risk considerations made during the planning process onshore, for instance the reason behind a planned specific sequence of activities (Sklet, 2013b).
- There should be stipulated guidelines that form a basis for and support uniform practice of use of the tool between the platform managers (Sklet, 2013b).
- The tool itself should be a robust information surface with an interface that is built up like other tools used in the industry or the specific company it is intended for. This may facilitate user friendliness, as the user(s) will recognise the basic layout. This is also believed to reduce misuse and help the user(s) get started.

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[2] § 21 of the Facilities Regulations require that information systems be dimensioned for both normal and critical situations. This is not, as such, within the limits of this master's thesis.

- It should be visible which factors that are not covered by the tool in the tools documentation (Sklet, 2013b).

In addition, remembering chapter 2.2.1 Occupational risk vs. major accident risk, the tool shall be focused on managing major accident risk.

3.6 Users of the tool

When defining the users of the new risk control tool it is pertinent to evaluate what personnel are closest to hazards. Kaarstad et al. (2010, p. 10) present "decision settings based on two underlying dimensions":

1. Proximity to the hazard, to distinguish between actors at the sharp end and those at the blunt end.
2. Level of authority, in the formal sense that actor A has a higher level of authority than actor B if A is entitled to issue orders, instruction or directives to B, but not vice versa.

As the illustration by SINTEF (Rosness et al., 2010) in Figure 3.2 shows, the captain, who in this case is the platform manager, is the one closest to hazards with a certain amount of decision-making authority.

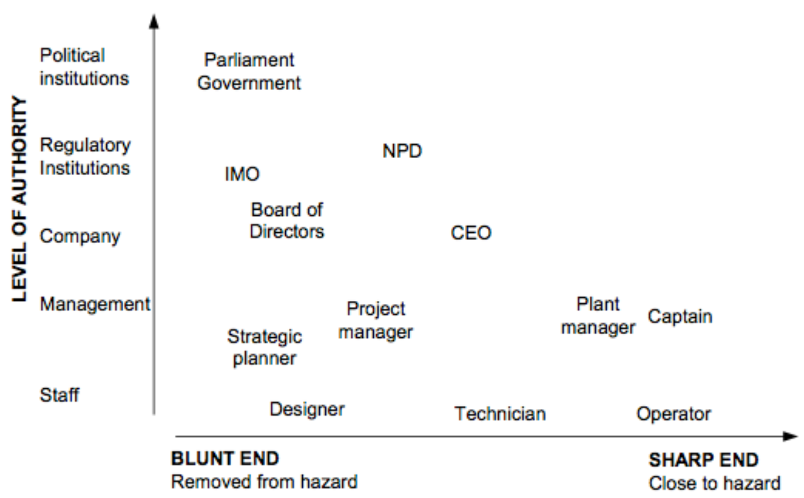


Figure 3.2: Two dimensions for characterising setting for safety related decision-making, Rosness et al. (2010)

The platform manager should thus be considered as one of the users of the tool, as he is close to hazards and has decision-making authority. On a day-to-day basis the management of the platform stipulate work permits (WPs) for the activities that are to be performed aboard the platform (Vinnem, 2013a). These WPs require that risk considerations be performed (Fløtaker, 2013a). In addition, meetings are held on a daily basis between the management offshore and the management and support staff onshore (Statoil, 2013a). During these meetings, general planning of activities take place, as well as a review of work that have been performed (Statoil, 2013a). In relation to Figure 3.2, Vinnem (2013c) states that the onshore management, i.e. the blunt end, has a long term planning horizon, while the offshore management at the sharp end has a more short-term planning horizon. Even though there is in fact a huge gap between the planning done onshore and the planning done offshore (Vinnem, 2013b), the management onshore is in fact involved in the planning of operations and activities offshore, and should thus also be considered as user(s) of such a tool. The tool can thus also be used for long term planning by the management and support staff onshore (Vinnem, 2013c).

3.7 Decisions in need of support

As desired by PSAN (2011a), the decisions to which the tool should provide support should be addressed when assessing the possibilities of, or creating, tools that analyse, assess and manage risk. The first of the following three subchapters address typical decisions that are proposed addressed during the development of a "Living Risk Analysis". The second subchapter presents an ex-platform managers view of what are the most important decisions the management of the platform makes where the information on barrier condition is of importance, as well as how risk considerations come into these decisions. The third subchapter presents a top management view on this topic.

3.7.1 Decisions proposed to be addressed by a "Living Risk Analysis"

Vinnem and Haugen (2012) have prepared a pre-project report for Gassco investigating the possibilities of developing a "Living Risk Analysis". The "Living Risk Analysis" has the purpose of providing "input to relevant decisions relating to planning and execution of maintenance and operational issues" (Vinnem and Haugen, 2012, p. 5) utilising instantaneous risk levels. The project recognised several decisions that typically could benefit from a "Living Risk Analysis" (Vinnem and Haugen, 2012, p. 9):

Decisions during planning of maintenance and modifications:

- If a barrier system has to be taken out for maintenance, are the remaining barriers sufficient to continue production?
- How many and what types of manual interventions in process systems can be planned to be carried out simultaneously within a specified area?
- Which hot work activities may be carried out in combination with other operational activities in view of the current barrier status?
- How can a programme of simultaneous activities be planned with necessary separation in time and/or space?
- What changes of maintenance and inspection intervals may be implemented?
- Planning of maintenance operations to replace defect barriers (e.g., leaking valve)
- Replacement of maintenance contractor with personnel with long history by new contractor without any history on installation

Decisions during day-to-day operational management:

- Decision whether to shut down production or continue production, if a severe defect is discovered on a barrier, for instance an isolation valve with a severe internal leak rate
- Decision whether to evacuate non-essential personnel, if a serious operational condition occurs, and in view of applicable weather forecasts
- Preparations for and implementation of replacement work, after it has been planned, of the defect barrier element
- How many and what types of manual interventions in process systems can be carried out simultaneously?
- Decisions to postpone updating of installation/plant specific documentation

A large selection of the abovementioned decisions are decisions that are desired answered with the outlined new risk control tool.

3.7.2 Decisions stated by a former platform manager

In a meeting with a former platform manager of the installation Statfjord C, namely Jan Morten Ertsaas, the following questions were asked:

1. Which are the most important decisions the management of the platform makes where the information on safety barrier condition is of importance?
2. How does risk considerations come into these decisions?

Ertsaas (2013) states that during his days as a platform manager five years ago, it was not such great focus directly on barriers as there is today. It was however focus on barriers related to handling hydrocarbons specifically. Ertsaas (2013) went on and stated that even though it was not such great focus on barriers, this shall not be taken as a sign of barriers not being used in the planning of activities.

In relation to question 1, Ertsaas (2013) states that the most important decisions the management of the platform makes where the information on safety barrier condition is of importance are related to the planning of activities and during operational management. In relation to the planning of activities, as a platform manager Ertsaas states that his work mostly involved approving (or not) WPs on WP level 1. This was performed during meetings where all "first line managers" participated. Presented with the same decisions as presented in the previous chapter, chapter 3.7.1, Ertsaas (2013) confirmed that these decisions are those that are of great importance to be made by the platform management. Regarding important decisions made by the platform management where information on safety barrier condition is of importance, Ertsaas (2013) focused on most of the decisions stated by Vinnem and Haugen (2012), that are presented in chapter 3.7.1, during the meeting.

In relation to question 2, Ertsaas (2013) stated that when such decisions were to be made, certain risk considerations would be performed. These considerations focused mainly on (Ertsaas, 2013):

- The condition of the safety barriers, and that the needed barriers were in place.
- Plant status.
- Simultaneous activities.
- The disconnection of barriers like bypassing gas detection or fire detection systems.
- Extraordinary measures.
- Mapping on drawings of the installation of the activities that were to be performed.

3.7.3 Decisions stated by an executive vice president

In an interview, Øystein Michelsen (2013a), Executive vice president, Development and production Norway, Statoil, was asked; which are the most important decisions the management of the platform makes where the information on barrier condition is of importance?

Michelsen (2013a) states that the most important decisions the management of the platform makes, where information on safety barrier condition is of importance, is during the planning of activities. More specifically the most important decisions are related to all activities involving gas carrying systems and/or equipment. Moreover, decisions during planning of special activities such as lifting over gas carrying systems and/or equipment, and especially heavy lifting, requires such information. Such activities are considered to bring with them great major accident risk potential. Michelsen (2013a) adds that such an activity is technically not within the law, but that there are situations and instances where such activities occur and instances when it is inevitable.

Furthermore, Michelsen (2013a) states that heavy lifting activities are performed in the range of or close to every second minute on the NCS, if one add them all together. It is due to this high frequency that he would state that this is one of the most important activities that require decisions upon and subsequently are in need of information on barrier condition.
Michelsen (2013b) states that other activities that carry high risk, and which Statoil focus and work on to control risk offshore, are ship arrivals, helicopter trips and major maintenance operations or turnarounds. Statoil has 34 platforms and more than 15 rigs operating today. Every year, 12.000 helicopter trips are performed, so helicopter safety is a very important issue. Furthermore, every year there are 15.000 cargo arrivals by vessels that represent a significant part of the risk that they have to handle every day. In addition, around 20 major maintenance operations or turnarounds are performed every year. These major maintenance operations or turnarounds place the installations in special situation with high activity level and also some kind of time pressure, Michelsen states (2013b). This is why Statoil spend a lot of time and effort on improvements, both involving Statoil employees but also a large number of contractors and suppliers.

When asked what risk considerations come into the decisions related to such activities, Michelsen (2013a) states that the focus on simultaneous activities are, as he considers, one of the most important aspects to assess during the planning of such activities, in addition to barrier condition. Michelsen (2013a) states furthermore that Statoil already have a system in place for management of simultaneous activities. He states further that it is important to note and manage the risk of the sum of the simultaneous activities. This is why such considerations are important to perform beforehand of an activity. In addition, Michelsen (2013a) states that Statoil uses a common action pattern called the *A-standard*, a best practice, when preparing, performing and evaluating work tasks. The *A-Standard* is presented in chapter 4.8.5.

3.8 Situations of use of the tool

As described in chapter 3.3, the tool should provide decision-support enabling the decision-maker(s) to decide on a day-to-day basis whether activities can or cannot be performed. This shall be performed by utilising amongst other the information on the state of the safety barriers, in addition to other information found pertinent for the decision to be educated. Examples of such activities are maintenance / modifications, hot work, cold work, marine operations etc. In addition, the tool described in this thesis can also be used during long-term planning onshore of activities offshore (Vinnem, 2013c).

A new tool for risk control, such as this, should also be focused on bridging gaps found in the industry it is intended for. As mentioned in chapter 3.1, a questionnaire survey (Vinnem et al., 2010) carried out for PSAN as a supervisory activity in 2009 revealed that the current risk analysis studies employed by the sector were not utilised "as input to day-to-day decisions on installations/plants about minor modifications, maintenance and intervention activities" (Vinnem and Haugen, 2012, p. 4). Such a tool should thus incorporate functions that allow for decision support in such situations.

3.9 How should information be communicated?

One way of illustrating how something is communicated is to consider what is to be communicated and what its intended use is. The intended use, as described in chapter 3.3, is to provide decision support to the decision-maker(s) on a day-to-day basis in the situations described in chapter 3.8. What is intended to be communicated can be described as input to a decision-making process where it should be determined to perform or not to perform an activity on a basis of amongst other information on the state of safety barriers. The following two subchapters discuss communication of indicators, and short-term risk and tolerance limits. Furthermore, examples of information are given in chapter 3.10 and 3.11. In addition, chapter 3.11 also focuses on the sources of information.

3.9.1 Communication of indicators

For the tool to provide installation specific day-to-day decision support, it is important that the information input to the tool as well as the information displayed to the end user is valid at installation level and is up to date. Information that is valid at a national level, like the indicators found in RNNP (PSAN, 2012e) that is based on incidents that have happened nationally on a yearly basis, are considered as too infrequent at a specific installation level to provide useful information to the tool and subsequently to the decision-maker on a day-to-day basis. It is therefore believed to be more suitable to use installation specific information (Vinnem, 2011). Proactive or leading indicators at an installation level can also be suitable. These indicators are also believed to be valid at company level. However, this does not mean that the technical systems (or barriers/-systems) monitored in the RNNP process should be excluded. Nor does it mean that what is measured on the barriers/-system in the RNNP process should be excluded.

Hopkins (2007, p. 9) presents the HSE´s guide definition of lagging and leading indicators:

> The leading indicator identifies failings or 'holes' in vital aspects of the risk control system discovered during routine checks on the operation of a critical activity within the risk control system.
>
> The lagging indicator reveals failings or 'holes' in that barrier discovered following an incident or adverse event. The incident does not necessarily have to result in injury or environmental damage and can be a near miss, precursor event or undesired outcome attributable to a failing in that risk control system

By mainly relying on leading indicators, the tool will present indicators that change before the risk level is further changed by introducing an activity. By the definition given above, relevant lagging indicators of more frequent incidents on an installation would also be considered as relevant to present to the user.

3.9.2 Communication of short-term risk and tolerance limits

When deciding upon whether an activity should be performed or not, the tool could also incorporate a function enabling the decision-maker(s) to consider the total risk of the platform against acceptance criteria for risk, if such a function could be easy to use. As the tool is to be used on a daily basis, such a function must be capable of showing transient levels of risk over shorter periods of time, partly due to the fact that activities performed on the installation may have a time span in the range of a few hours to several days (Vinnem and Haugen, 2012, p. 6). Furthermore, Vinnem and Haugen (2012, p. 5) list a number of transients that "will be involved in a living risk analysis" (Vinnem and Haugen, 2012, p. 5):

- Changes in risk levels when modifications are introduced
- Temporary variations in risk levels over time in relation to average level.
- Minor changes that individually are too small to have significant impact, but which may accumulate over time.

Moreover, regarding shorter periods of time, Vinnem and Haugen (2012) state that a time increment of 12 hours to as little as one hour could be sensible for a "living risk analysis". Such a requirement has to be made so that short-term risk and short-term risk peaks can be captured. Regarding how risk should be expressed, Vinnem and Haugen (2012, p. 6) state that:

> It is considered that the FAR or PLL or some equivalent values are not appropriate to express the instantaneous risk level. It must be assumed that very few changes will have significant impact if the FAR or some equivalent is used. When the total FAR for an installation/plant is used, the values will be diluted with other risk contributions (e.g. from occupational accidents), also from the risk levels for the shifts and personnel groups that are not exposed to those changes. FAR or equivalent is normally not suitable.

Instead of using FAR or PLL or similar, Vinnem and Haugen (2012, p.7) propose to rather use either:

- the frequency of specific accident scenarios with a given severity (controlled fire, uncontrolled fire, explosion, strong explosion, etc.)

- frequency of loss of main safety functions

In addition, Vinnem and Haugen (2012, p. 7) state that it "may (…) be appropriate to use different parameters for expression of the different 'instantaneous' risk levels". Furthermore "A set of parameters is probably going to be necessary, not only one, also depending on the type of installation or plant, the actual problem, type and scope of the analysis, etc" (Vinnem and Haugen, 2012, p. 7).

Short-term transient levels of risk also require that short-term acceptance limits of risk be established. Vinnem and Haugen (2012, p 12) state that "The risk acceptance criteria that are being used by the industry are related to 12 month average values, and are therefore not usable when durations of much shorter periods are considered". Vinnem and Haugen (2012, p. 12) go on and state that:

> The acceptance limits for the most exposed individuals are usually around FAR = 25-30 (per 10^8 exposure hours). It may be expected that equivalent FAR values for short duration activities (if assumed to continue for one year) will be in the range up to FAR = 100-1000 (…), which certainly underlines that a risk acceptance limit of FAR = 30 is not usable.

However, Vinnem and Haugen (2012) propose that to phrase such a limit, as a "tolerance limit" rather then as a "risk acceptance limit" could resolve this problem, as limits for transient levels of risk are not required by legislations. Vinnem and Haugen (2012, p. 12) go on and state that:

> It is far from straightforward to formulate such tolerance limits for short duration activities. There have been attempts to formulate such values, with limited success. Puglia & Atefi (1995) confirm that this is a challenge, also for nuclear power plant applications.

Nevertheless, the development of such a tolerance limit should be possible "either from comparing the risk during a transient increase with the accumulated (or average) of the previous 12 months, or by taking the risk level in acceptance transients (such as helicopter transport) as a guidance" (Vinnem and Haugen, 2012, p. 12). Furthermore, NORSOK Z-013 (2010, p. 67) states that RAC for time limited risk increase have to reflect:

- the duration of the period with increased risk,
- the peak level of risk during this operation,
- whether the risk increase is local or global for the installation,
- whether the risk increase affects the different personnel groups in the same way or differently.

Vinnem (2013c) states that the risk management tool used at Kårstø gas plant is, as he sees it, the only example of such a short-term tolerance limit being used. The risk management tool used at Kårstø gas plant, as well as the tolerance limits used at Kårstø, is presented in chapter 4.8.4.

3.10 What should be presented to the user(s)?

Building on, amongst other, the premises from the previous chapters, the following is considered to be relevant to present to the user(s) as decision support:

- Area specific information on the state of the safety barriers that are directed specifically against major accidents. See chapter 3.12 and chapter 4.
    - Relevant indicators and information that is suitable for helping the decision-maker make a decision, e.g. valve status (open / shut) from automatic transponders (Fløtaker 2013d and Vinnem, 2013c).
- A "map" of the platform
    - with a break down structure, or "zoom function", as follows: the installation – deck – area – system. Each level being able to show different kind of information.
    - that should be able to amongst other show P&ID drawings etc
    - showing active dispensations
    - showing work / activities that are in progress, and work / activities that are to be performed. This work can be colour coordinated with for instance hot work and high risk activities and/or work being red, and cold work and all other activities and/or work being blue.

  - displaying the number of activities in the same area
- Current weather and weather forecast.
- Operational data.
- Operating limits and preconditions used in QRA.
- Preconditions stipulated and risk considerations performed during the onshore planning of activities.
- Decision-making criteria and guidance, as further discussed in chapter 5.
- Ideally, a simulation function for which the user(s) can simulate the effect a specific activity brings in time and space (Fløtaker, 2013a). [3]
- The overall risk of the platform. A function within the risk control tool enabling the user(s) to consider the total risk of the platform against tolerance limits for risk, given that such a model can be developed.

"System" is included in the break down structure of the map to be able to pinpoint a specific work task on a specific system that can span over multiple decks on the platform. In addition, a map of the platform should be able to illustrate the effect of activities performed across multiple decks on the installation.

3.11 Information input and sources of information

As discussed earlier in chapter 3, a new risk control tool should, as far as possible, rely on and take advantage of frequently updated and reliable information from other systems already put in place by the operator. The following subchapters describe the type of information that goes into the risk control tool, and the sources from which information can be gathered in the operational phase. Moreover, company specific tools in relation to some of the following subchapters are presented in chapter 4. In addition to the following subchapters, current weather condition and weather forecast are considered as relevant information that should be gathered from reliable sources.

[3] An actual simulation function is not within the scope of this thesis, and will thus not be addressed further than to state that such a function ideally would be preferred.

3.11.1 QRA

Underlying assumptions used in QRA, as for instance the maximum number of drilling operations per year, should be illuminated through such a risk control tool (Sklet, 2013b). QRAs also stipulate the acceptable level of risk, which also is an important input to the tool. In addition, area risk charts are also important input to the risk control tool from QRAs.

3.11.2 Audits, inspections and maintenance

For barrier status to be known, the measurement parameters described by the PRs, which are stipulated in the output from a risk management process, have to be monitored. This is handled by the company or the operator of the installation through maintenance programs and safety audits, and is reported through audit management and reporting systems (DNV, 2012b). During inspections, tests of safety critical equipment may be performed. In addition, technical and operational condition may be assessed and verified during audits. Verification of performance is illustrated in chapter 2.7.3. These activities of audits, inspections and reporting require the expert judgement and knowledge of the personnel involved like division managers and/or educated and experienced staff (Fløtaker, 2013a). Company specific tools for assessment and/or reporting of status of safety barrier, technical and operational condition, like for instance Statoil's TIMP, TTS and OTS, are presented in chapter 4.8. In addition, maintenance programs and maintenance administration systems put in place to maintain barrier performance can contain information on important indicators regarding safety critical equipment (Fløtaker, 2013a). Examples of indicators are presented in chapter 4.

3.11.3 Operational data

The management of an offshore platform have to balance safety objectives and production objectives on a regular basis. To achieve such balance, the management must comply with predefined operating limits like "minimum requirements for equipment, e.g. must have one pump running and one on-line spare, or must not run without gas detection in place" (Hayes, 2012, p. 425). Sources of technical information concerning such requirements as well as operational data are thus important sources for such a risk control tool.

3.11.4 Accident and incident

Chapter 3.9 suggests that information valid on a national level, like the indicators found in RNNP work (PSAN, 2012e), is too infrequent at a specific installation level to provide useful information to a decision-maker. However, relevant lagging indicators of more frequent incidents or accidents on an installation level or a company level can be considered relevant to present to the user(s) of the tool (Fløtaker, 2013a). The information from such incidents can provide trends in performance over shorter periods of time. Information found in tools for incident reporting can thus be of importance and should be communicated via the risk control tool. As the companies also report such information to RNNP, the data should be quite available. Examples of such information can be hydrocarbon emissions and their size and frequency, and incidents with barrier breaches.

3.11.5 Dispensations

Handling of dispensations is an imperative activity to operate safely (Fløtaker, 2013a). With regards to a new risk control tool, some questions about the dispensations arise:

- Does the dispensation state something about what can or cannot be performed, when the dispensation is "active"?
- Do the dispensations state some operational requirements or limits?
- Does the dispensation contain important information about systems or barriers that are put out of operation?
- Is there anything in these dispensations that affect the safety barriers?

It is important that the decision-maker is aware of such information as listed above, as it can have a direct effect on the decision itself. Operators on the NCS, like for instance Statoil, already have tools for managing dispensations (Lunde, 2012). There is however a lot of information contained within such a tool. Not all information contained in such tools can be considered as vital and in need of presentation to the decision-maker. What is considered to be useful to present is information affecting the safety barriers as well as temporary deviations affecting activities. Furthermore, the dispensations presented by the risk control tool could be further limited to the technical and organisational safety barriers (Vinnem, 2013a). An example of this being that the actual design of the installation does not change considerably from day to day and should thus not be considered as important input.

If the tool is able to present vital information on dispensations, then it can also be considered as helpful during handover between managers. Fløtaker (2013a) describes a scenario during oral handover between managers: A platform manager states some important dispensations to the person who takes over after him. Furthermore, the person who takes over states some other dispensations in addition to those stated by the first platform manager. Now, are all dispensations addressed at the next handover? DNV has the understanding that this not necessarily always is a fact (Fløtaker, 2013a). Thus, if the tool is able to gather the most important information from systems put in place for reporting such dispensations, a function where the user could access this information could be considered as quite helpful. This could prevent the loss of information during handover, as well as the decision-maker not having to "dig through pages" of dispensations to find the vital information needed.

3.11.6 Work permits

On a day-to-day basis the management of the platform stipulate WPs for the jobs that are to be performed aboard the platform (Vinnem, 2013a). These WPs require that risk considerations be performed (Fløtaker, 2013a). The purpose of WPs is to ensure (BP Norway, 2013, p. 53):

- that injuries, accidents and undesired incidents do not occur while a job is being performed
- that simultaneous activities do not cause any danger
- the operational safety of the task performed

There are two levels of WPs. Level 1 addresses all high risk work and have to be approved by the platform manager. Level 2 addresses all other work and has to be approved by the person responsible for the system (Sklet, 2013a and BP Norway, 2013). Table 3.2 stipulate examples of work that require WPs.

WP level 1	WP level 2
• Hot work class A • Hot work class B in classified area • Entry • Disconnection of safety systems • Work on hydrocarbon-carrying systems • Pressure testing • Work over open sea • Work involving hazardous chemicals • Work involving radioactive substances • Work involving low-specific activity scale • Well operations / well interventions • Work involving explosives • Critical lifting operations • Other critical work operations	• Mechanical work • Work on electrical equipment • Work on automation, telecomm. and computer systems • Routine work on hydrocarbon-carrying systems where there is no risk of hydrocarbons being released • Scaffolding • Paint work using brush and roller • Isolation work • Hot work class B in unclassified area

Table 3.2: Work that require work permit, based on excerpts from BP Norway (2013)

The WP form, that is to be filled out, contains important information a new risk control tool can take advantage of. The following are examples of such information (BP Norway, 2013):

- Type of work
- Task
- Location:
  - Installation
  - Location/module
  - Deck
  - Zone
- Work order number
- From date / hour
- To date / hour
- Supervisor / technician
- Information on operation- and safety preparations
- Remarks / requirements
- Precautions prior to / during work execution

As can be seen from the list above, a WP form can stipulate the type of work in time and space, and stipulates thus the characteristics of the activity that is to be performed. This can also be useful for a function within the risk control tool that can "map" such information. For a complete WP form for level 1 and 2, see Appendix B – Work Permit form level 1 and Appendix C – Work Permit form level 2.

3.11.7 Training and exercises

Training and exercises can reveal weaknesses in barriers/-systems that are not uncovered during manual inspection or testing (Madsen, 2006). An accident scenario played out by the personnel on the installation, utilising the procedures, tools and equipment that would have been used during an actual event, can uncover weaknesses in physical, human/operational and technical barriers/-systems. Furthermore, a worst-case scenario fully "played out" gives the personnel a chance to practice procedures that are normally only stipulated on a piece of paper, and a chance to train for an emergency response. Uncovering such weaknesses as mentioned above is crucial for continuous safe operation, and the weaknesses uncovered should be treated during the operational phase.

In addition, training for special operations and activities, in e.g. simulators or under safe conditions, can uncover contingencies that have to be addressed and followed closely when the operation or activity is actually to be performed on the installation. Such contingencies should be presented to the user(s) of the risk control tool. Moreover, training of personnel is, in itself, an essential activity for operating safely.

3.11.8 Onshore planning

Meetings are held on a daily basis between the management offshore and the management and support staff onshore (Statoil, 2013a). During these meetings, general planning of activities take place, as well as a review of work that has been performed (Statoil, 2013a). Many of the activities performed offshore are planned onshore (Sklet, 2013b). A former platform manager, who worked on Statfjord C in the North Sea, states that he missed having more information about the planning performed onshore, especially more information from the planning done by sub suppliers, during his days aboard the installation (Ertsaas, 2013). It is vital that preconditions stipulated and risk considerations performed during the onshore planning are illuminated through such a risk control tool (Sklet, 2013b). An example of this is for instance the reason behind a specific sequence of activities, like why two activities cannot be performed on the same day.

3.12 Basis for selection of barriers and indicators to monitor

Chapter 3.11 stipulates the type of information, along with sources of information, that is considered to be essential for the tool and/or, in turn, the decision-maker to have access to. There is today, in theory, almost no limit for what amount of information computers may store, manage or compute on. An advanced new tool can thus have complex models and calculation capabilities built in to it that are able to for instance run probabilistic calculations etc., that can give a somewhat reasonable prediction of the risk and the outcome of an event or activity if the information base is extensive and accurate enough.

There are however certain limitations and/or restrictions that have to be made considering the tool described throughout this chapter. Complex socio-technical equipment or tools require interactions with human beings. It is thus pointless to present endless amount of information to the user(s), which in turn do not have the same capabilities as a computer. In addition, the use of the tool is restricted to the operational phase under normal conditions, i.e. before an initiating or accidental event. The tool is also to be aimed at management of major accident risk on a day-to-day basis.

3.12.1 Selection of barriers and barrier properties to monitor

There are many safety barriers, for instance technical, operational and organisational, put in place on an offshore installation to reduce the probability and/or limit the harm of accident situations (PSAN, 2012b). As the tool is focused on management of major accident risk, the barriers monitored should also be limited to barriers against major accidents. Operational barriers, like design and construction, operation and maintenance, procedures and also modifications, are barriers that do not show the same transient or dynamic behaviour as technical and organisational barriers (Vinnem, 2013a). The specific design of the installation does for instance not change dramatically from day to day. Thus, focus should be on technical and organisational safety barriers.

With regards to transient behaviour of safety barriers, the information collected on technical safety barriers can also be limited. Given information on for instance an emergency shut down valve (ESDV), what are the most transient properties of this valve? Properties of the valve can include corrosion resistance, fire resistance, closing time, ability to withstand load / pressure and so forth. Take for instance the time it takes to close the valve. This can be found by performing a closure test. An elapsed time of 10 seconds might be normal for a specific ESDV to close, whereas 2 minutes is abnormal. Such an increase in closing time may develop over a short period of time, and is thus considered as short-term transient behaviour of one of the properties of the valve. Information on this type of transient properties should thus be collected and communicated. On the other hand, the fire resistance of the ESDV may not be exposed to such transient behaviour over a shorter period of time. The inherent properties of passive fire protection, like fire resistant paint or paint that expands or turns into some sort of foam, may degrade over a longer period time. The ESDV may thus have transient closing time while the fire resistance stays the same over a shorter period of time. The principle could likewise be used on other properties; as for instance the most transient "property" measured at Kårstø gas plant is simultaneous activities in the same area of the plant (Vinnem, 2013a).

As a result, information could be collected and presented on the most transient properties and/or behaviour of the safety barriers directed against major accidents that have a possibility for inherent transient behaviour of properties over a shorter period of time. A classification of barrier elements according to their transient properties / behaviour could thus be a solution. It is also important to note that some of the properties of the safety barriers may be linked. For instance, the more corrosion has degraded a specific physical barrier, the less pressure it will be able to withstand. Such links between properties should be considered when deciding which properties are exposed to the most transient behaviour. The transient behaviour of a property of a safety barrier could thus for instance be a function of other properties of the same safety barrier. It should be noted that this does not mean that focus should be removed from long-term weaknesses, as it is important to have control on long-term weaknesses (Fløtaker, 2013d).

3.12.2 Selection of performance indicators

In a presentation addressing leading and lagging key performance indicators (KPIs), Vinnem (2011) presents criteria for good indicators as shown in Table 3.3.

Criteria	Description
Combination of lagging and leading indicators	• Leading often preferred over lagging • Both should be used, for different needs • Number of indicators kept at a reasonable level (max 20-25?)
Easily observable performance	• Measurable by applying a recognized data collection method and scale of measurement • Usually expressed on a ratio scale of measurement • Limiting the data collection to those events with medium and large severity will usually improve the reliability significantly
Intuitive indicators	• What is measured is considered intuitively by the workforce to be important for the prevention of major accidents
Not require complex calculations	• Major hazard risk indicators should not require complex calculations (intuitiveness) • If the number of observations goes down, it should correspond to an improvement • If very complex calculations are required, the confidence may be lost
Not be influenced by campaigns that give conflicting signals	• Psychological and organizational reasons could in many cases result in a too low reporting
Reflect hazard mechanisms	Non given
Sensitive to change	Non given
Show trends	• Major hazard risk indicator should allow for early warning by capturing changes in a socio-technical system that have significant effects on accident risks • "Good" set of indicators reflects changes in risk as well as where improvement areas • Number of observations (incidents, barrier faults, etc) should for lowest level systems be in order of a dozen or so per period (year?)
Robust to manipulation	• The major hazard risk indicators should not allow the organization to "look good" by for example changing reporting behaviour, rather than making the necessary basic changes that reduce accident risk
Validity for major hazard risk	• Is the indicator a valid indicator for the major accident risk? • Is indicator actually measuring what we intend to measure?

Table 3.3: Criteria for good indicators, based on excerpts from Vinnem (2011)

4 EXISTING MEASURES, METHODS, PROCESSES AND TOOLS

4.1 Introduction

As discussed in the previous chapter, chapter 3, a new risk control tool should, as far as possible, rely on and take advantage of frequently updated and reliable information from other systems already put in place by the operator. There are a lot of factors that have to be considered in the process of "creating" a new tool. The subsequent subchapters review and present technical, operational and organisational barriers that are established to ensure safe operation of an offshore installation on the NCS, risk influencing factors (RIFs) recognised in the BORA approach, indicators found in RNNP and indicators proposed by DNV and OGP. In addition, a barrier performance panel is presented, and a method to establish an overall risk indicator is reviewed. Moreover, some company specific methods, processes and tools are reviewed at the end of the chapter. Indicators found in RNNP are included in this chapter to show which safety barriers and lagging indicators should be illuminated.

4.2 Safety barriers on offshore oil and gas installations

Technical, operational and organisational barriers are established to ensure safe operation of an offshore installation on the NCS. The following subchapters present barriers/-systems and elements that are required by NORSOK as well as stipulated by PSAN.

4.2.1 Safety barriers/-systems in NORSOK S-001

The NORSOK S-001 (2008) Technical safety standard is utilised by the petroleum industry in Norway, and is applicable to platforms on the NCS. The standard describes requirements for twenty individual safety barriers/-systems, including their role, interfaces, required utilities, functional requirements and survivability requirements. With *interface* it is meant "the interface with other safety systems and barriers" (NORSOK S-001, 2008, p. 6). Table 4.1 lists the safety barriers/-systems and their role according to NORSOK S-001 (2008).

Safety barriers/-systems	**Role**
Layout	Reduce probability and the consequences of accidents through location, separation and orientation of areas, equipment and functions.
Structural integrity	Withstand all load conditions under normal operation and also ensure structural integrity during dimensioning accidental events.
Containment	Prevent release of hydrocarbons, chemicals and/or toxic gases.
Open drain	Control of spills. Provide measures for containment and proper disposal of liquids.
Process safety	Control abnormal operating conditions to prevent possible hydrocarbon release.
Emergency shut down (ESD)	Prevent escalation of abnormal conditions into a major hazardous event and to limit the extent and duration of any such events that do occur.
Blow down (BD) and flair/vent system	- Reduce the pressure in process segments to reduced the risk of rupture and escalation in the event of a fire - Reduce the leak rate and leak duration and thereby ignition probability, - In some cases avoid leakage at process upsets, e.g. in case of loss of compressor seal oil/seal gas, - Route gases from atmospheric vent lines to safe location.
Gas detection	Monitor continuously for the presence of flammable or toxic gases, to alert personnel and allow control actions to be initiated manually or automatically to minimise the probability of personnel exposure, explosion and fire.
Fire detection	Monitor continuously for the presence of a fire to alert personnel and allow control actions to be initiated manually or automatically to minimise the likelihood of fire escalation and probability of personnel exposure.
Ignition source control (ISC)	Minimize the likelihood of ignition of flammable liquids and gases following a loss of containment.
Human – machine interface (HMI)	Provide system information presentation and means for operator interactions.
Natural ventilation and heating, ventilation and air conditioning (HVAC)	- Dilute gas concentrations and reduce the size of flammable gas clouds, - Dilute harmful concentrations of smoke or toxic gases, - Ensure acceptable equipment environment.
Public address (PA), alarm and emergency communication	Warn and guide personnel as quickly as possible in the event of a hazardous or emergency situation.
Emergency power and lighting	Provide: - electrical power for specified consumers when main power generation is being shut down; - emergency electrical power supply for a specific period of time for systems required being in operation during or after a major hazard incident.
Passive fire protection (PFP)	Ensure that relevant structures, piping and equipment components have adequate fire resistance with regard to load bearing properties, integrity and insulation properties during a dimensioning fire, and contribute in reducing the consequences in general. Fire divisions shall ensure that a dimensioning fire and explosion does not escalate into surrounding areas.
Fire fighting systems	Provide quick and reliable means for fighting fires and mitigate explosion effects.
Escape and evacuation	- Escape routes: ensure that personnel may leave areas in case of a hazardous incident by at least one safe route and to enable personnel to reach the designated mustering area from any position on the installation. - Evacuation system: ensure means of safe abandonment of the installation

Safety barriers/-systems	Role
	for the maximum personnel on board, following a hazardous incident and a decision to abandon the installation.
Rescue and safety equipment	Provide personnel with suitable and sufficient protective equipment to effect rescue of personnel, enable them to reach escape/evacuation points and, if necessary, to maximise the chance of a successful recovery from the sea.
Marine systems and position keeping	- The ballast system shall provide easy and reliable facilities for ballast water distribution in order to maintain control of the floating offshore installation during routine operations and emergency situations, in terms of stability, heel, trim and draft and ensuring that hull stresses do not exceed the design strength criteria. - The bilge system shall provide easy and reliable facilities for pumping from and draining of watertight compartments. - The weight and stability monitoring systems shall ensure that weights do not exceed the structural capacity and that weight distribution is such that stability curves are not exceeded. - The weather- and watertight closing means such as doors and hatches shall maintain the watertight divisions during all operating conditions. - The position keeping system shall enable the floating installation to maintain position and heading within given operational limits.
Ship collision barrier	Reduce the risk for ship collisions.

Table 4.1: Overview of safety barriers/-systems and roles in NORSOK S-001, based on excerpts from NORSOK S-001 (2008)

It should be noted that the barriers/-systems listed in Table 4.1 above are closely related to the PSs described in chapter 2.7.2.3.

4.2.2 Barriers in NORSOK Z-013

The NORSOK Z-013 (2010) Risk and emergency preparedness assessment standard covers risk for major accidents, and states the minimum collection of barriers that have to be included in a QRA that addresses at least nine different initiating events (IEs). Table 4.2 lists the IEs and the minimum selection of barriers that are stipulated by NORSOK Z-013 (2010).

In Table 4.2, * refers to safety systems and • refers to safety functions.

Initiating event	Barriers
Process accidents	Detection Emergency shutdown system and blowdown Control of ignition Control of spills Emergency power system Fire and gas system Active fire protection Passive fire protection Explosion mitigation and protection system Evacuation, escape and rescue Segregation of main areas Structural integrity and stability
Riser/landfall and pipeline accidents	Detection Emergency shutdown (ESD) system and blowdown Control of ignition Fire and gas detection system Fire protection Evacuation, escape and rescue Structural integrity and stability
Accidents in utility system	No barriers or safety systems listed
Storage accidents	Bunds * Passive and active fire protection * Pressure relief systems * Purge gas * Water curtains etc. *
Blowouts and well releases	Riser margin Mud balance system Pressure balance system Diverter system Control of ignition Control of spills Emergency systems related to well operations and drilling Annulus safety valve (ASV) Blowout preventer (BOP) X-mas tree Down hole safety valve (DHSV) Barrier functions as for process accidents
External impact – Ship collisions	Planned operational restrictions for vessels Collision resistance of the facility (included risers) Planned traffic surveillance Planned emergency preparedness measures
External impact – Falling and swinging loads	No barriers or safety systems listed
External impact - Other	No barriers or safety systems listed
Helicopter accidents	No barriers or safety systems listed
Marine hazards	Structural integrity • Buoyancy and/or stability • Escape and evacuation •
Environmental consequences	Detection Drain systems etc.

Table 4.2: Overview of initiating events and corresponding barriers in NORSOK Z-013, based on excerpts from NORSOK Z-013 (2010)

4.2.3 Operational and organisational barrier elements

With regards to barrier management, PSAN (2011b) presents operational and organisational barrier elements in the document "*Principles for barrier management in the petroleum activities*". In connection with the presented barrier elements, PSAN makes sure to specify that it is not the label one puts on the different barrier elements that are important, but that the barrier functions are upheld. The operational and organisational barrier elements presented by PSAN (2011b) are listed in Table 4.3 below.

Organisational barrier elements	Operational barrier elements
• Competence • Interaction / Communication • Work practice • Monitor / Check / Verify • Documentation • Resources, capacity • Work load • Planning • Responsibility and roles	• Design and construction • Operation and maintenance • Procedures • Modifications

Table 4.3: Operational and organisational barrier elements, based on PSAN (2011b)

On the other hand, DNV does not see procedures as barrier elements (Fløtaker, 2013a). A procedure that is good, well known and followed is, by DNV, seen as a risk influencing factor (Fløtaker, 2013a).

4.3 Risk Influencing Factors

A recently developed approach for QRA, the BORA approach (Vinnem et al., 2007), includes human and organisational factors in addition to technical factors in operational risk analysis. The BORA approach was developed during The Barrier and Operational Risk Analysis Project between 2003 and 2006, and is a QRA approach modelling the total risk of an accident scenario using, amongst other, RIFs.

Sklet (2006, p. 496) defines RIFs as factors that have an indirect effect "on the occurrence and/or consequences of an undesired event or accident". These differ from barriers that ought to "have a direct and significant effect" (Rausand, 2011, p. 496). In the BORA approach, RIFs are given a weight as to be usable when calculating the frequencies or probabilities of basic initiating events using Risk Influencing Diagrams (RIDs). Table 4.4 presents the RIFs included in the BORA approach, as well as their description.

RIF group	RIF	Description
Personnel	Competence	Cover aspects related to the competence, experience, system knowledge and training of personnel.
	Working load/stress	Cover aspects related to the general working load on persons (the sum of all tasks and activities)
	Work environment	Cover aspects related to the physical working environment like noise, light, vibration, use of chemical substances, etc.
	Fatigue	Cover aspects related to fatigue of the person, e.g., due to night shift and extensive use of overtime
Task	Methodology	Cover aspects related to the methodology used to carry out a specific task.
	Task supervision	Cover aspects related to supervision of specific tasks by a supervisor (e.g., by operations manager or mechanical supervisor
	Task complexity	Cover aspects related to the complexity of a specific task
	Time pressure	Cover aspects related to the time pressure in the planning, execution and finishing of a specific task
	Tools	Cover aspects related to the availability and operability of necessary tools in order to perform a task
	Spares	Cover aspects related to the availability of the spares needed to perform the task.
Technical system	Equipment design	Cover aspects related to the design of equipment and systems such as flange type (ANSI or compact), valve type, etc.
	Material properties	Cover aspects related to properties of the selected material with respect to corrosion, erosion. fatigue, gasket material properties, etc.
	Process complexity	Cover aspects related to the general complexity of the process plant as a whole
	Human Machine Interface (HMI)	Cover aspects related to the human-machine interface such as ergonomic factors, labeling of equipment, position feedback from valves, alarms, etc.
	Maintainability / accessibility	Cover aspects related to the maintainability of equipment and systems like accessibility to valves and flanges, space to use necessary tools, etc.
	System feedback	Cover aspects related to how errors and failures are instantaneously detected, due to alarm, failure to start, etc.
	Technical condition	Cover aspects related to the condition of the technical system
Administrative control	Procedures	Cover aspects related to the quality and availability of permanent procedures and job/task descriptions
	Work permit	Cover aspects related to the system for work permits, like application, review, approval, follow-up, and control
	Disposable work description	Cover aspects related to the quality and availability of disposable work descriptions like Safe Job analysis (SJA) and isolation plans
	Documentation	Cover aspects related to the quality, availability, and

RIF group	RIF	Description
		updating of drawings, P&IDs, etc.
Organisational factors	Programs	Cover aspects related to the extent and quality of programs for preventive maintenance (PM), condition monitoring (CM), inspection, 3rd party control of work, use of self control/checklists, etc. One important aspect is whether PM, CM, etc., is specified
	Work practice	Cover aspects related to common practice during accomplishment of work activities. Factors like whether procedures and checklists are used and followed, whether shortcuts are accepted, focus on time before quality, etc.
	Supervision	Cover aspects related to the supervision on the platform like follow- up of activities, follow-up of plans, deadlines, etc.
	Communication	Cover aspects related to communication between different actors like area platform manager, supervisors, area technicians, maintenance contractors, CCR technicians, etc.
	Tidiness and cleaning	Cover aspects related to the general cleaning and tidiness in different areas on the platform
	Support systems	Cover the quality of data support systems like SAP, etc
	Acceptance criteria	Cover aspects related to the definitions of specific acceptance criteria related to for instance condition monitoring, inspection, etc.
	Simultaneous activities	Cover aspects related to amount of simultaneous activities, either planned (like maintenances and modifications) and unplanned (like shutdown)
	Management of changes	Cover aspects related to changes and modifications

Table 4.4: Risk Influencing Factors and descriptions, based on excerpts from Vinnem et al. (2007)

As can be seen by comparing the organisational and operational barrier elements presented in chapter 4.2.3 with the RIFs presented in Table 4.4 above, the similarities are quite striking.

4.4 Barriers and indicators in RNNP

Annually, PSAN presents the trends in risk level in the Norwegian petroleum activity, both offshore and land based, in the RNNP report (PSAN, 2012e). "The RNNP process monitors risk trends with the aid of various methods, such as incident indicators, barrier data, interviews with key informants, working seminars and field work" (PSAN, 2012f). RNNP has collected data on major hazard precursors since 1996, and barrier data for major hazards has been collected since 2002. In the RNNP process, indicators for major accidents are established through the use of *defined hazardous and accident situations* (DFUs). The data is presented in graphs after *total fraction of failures* and *mean fraction of failures* have been calculated using (PSAN, 2012e):

$$\text{Total fraction of failures} = \frac{\sum_{j=1}^{n} x_j}{\sum_{j=1}^{n} y_j}$$

$$\text{Mean fraction of failures} = \frac{1}{n}\sum_{j=1}^{n}\frac{x_j}{y_j}$$

where n represents the number of facilities that have conducted tests for barrier element, x_j is the number of failures on facility j, and y_j is the number of tests conducted on facility j. Figure 4.1 below shows the mean fraction of failures for barrier elements related to production and process of hydrocarbons (HC), as presented and analysed in chapter seven, "Risk indicator for barriers against major accidents", of the RNNP report (PSAN, 2012f):

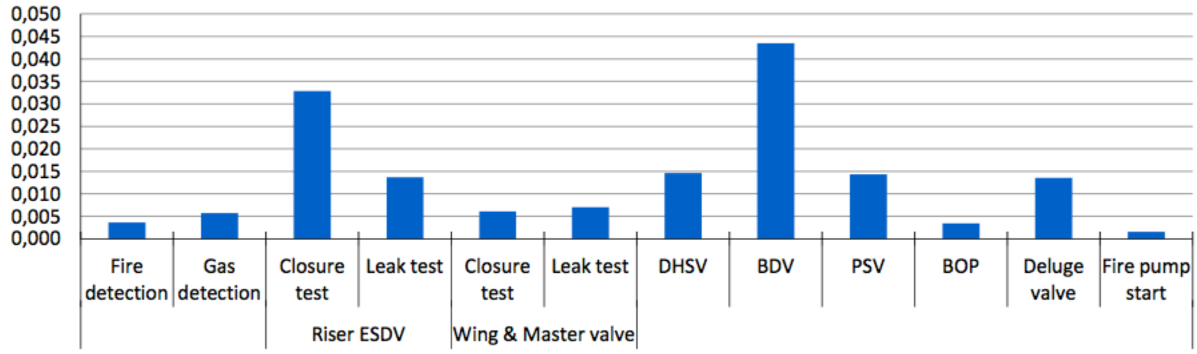


Figure 4.1: Mean fraction of failures for selected barrier elements related to hydrocarbons, production facilities, PSAN (2012f)

In addition, analysis is performed and data is presented on the following barriers connected with major accidents (PSAN, 2012e):

- Well integrity
- Marine systems
    - Valves in the ballast system
    - Closing of waterproof doors
    - Reference systems (movable facilities)
- Maintenance management
- Response time (evacuation drills)

Chapter six of the RNNP report (PSAN, 2012e) presents risk indicators for major accidents. Figure 4.2 below shows the number of reported DFUs distributed by categories.

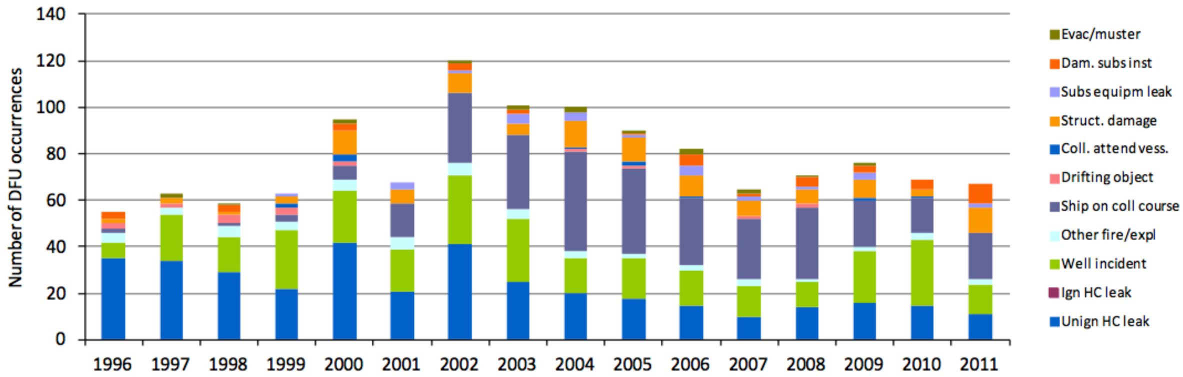


Figure 4.2: Reported DFUs distributed by categories, PSAN (2012f)

As can be seen from the figure, the DFUs *ship on collision course* (purple), *well incident* (green) and *un-ignited HC leaks* (blue) show a substantial amount of annual precursors.

4.5 Indicators and sources of data proposed by DNV

As stated in chapter 2.4, the state of operation is affected by the state of the barrier system. There are several factors influencing the condition of the barrier systems during operation, and thus the realisation of a barrier function is influenced by a lot of factors. Våge (2012) states that technical, human and organisational factors cause the reason for barrier degradation to be complex. This means that a number of different indicators and data sources must be monitored and followed closely as to verify that barrier functions are maintained and safe operations are ensured. DNV (2012b) proposes that the indicators and sources of data presented in Table 4.5 be monitored. In Table 4.5, # refers to "*number of*".

Indicators	Sources of data
• Total corrective maintenance on safety critical equipment • # errors / # tests (safety critical equipment) • Findings during inspection on safety critical equipment • Number of overrides of safety critical equipment • Open critical findings from audits • Remaining PM on safety critical equipment • Remaining tests of safety critical equipment • Remaining inspections of safety critical equipment • Remaining modifications on safety critical equipment • Accidents / incidents with breach of barriers and / or potential for escalation	• Maintenance program • Inspection program • Operational data • Accident and incident reporting • Training • Exercises • Etc.

Table 4.5: Indicators and sources of data proposed by DNV, based on DNV (2012b)

4.6 Key Performance Indicators proposed by OGP

The International Association of Oil & Gas Producers (OGP, 2011) has developed a recommended practice on Key Performance Indicators (KPIs) for the oil and gas industry. In this recommended practice, OGP (2011, p. 2) states that "Lagging indicators measure barrier defects (´holes´), events and consequences" and "Leading indicators maintain barrier strength, i.e. activities to maintain risk control systems".

The recommended practice is built up with a "four tier approach", where Tier 1 and 2 KPIs are implemented to assess company performance, and Tier 3 and 4 KPIs are implemented to monitor critical barriers at facilities. Furthermore, a Tier 3 KPI

> "records an operational situation, typically considered a 'near miss', which has challenged the safety system by progressing through one or more barrier weaknesses to result in an event or condition" (OGP, 2011, p. 18).

While a Tier 4 KPI

> "represents performance of the individual risk control barriers, or its components, within a facility's management system, and operating discipline. These KPIs are typically more leading and pro-active because they reflect activities of the company

directly associated with maintaining and improving its risk control barriers" (OGP, 2011, p. 19).

Within the recommended practice, OGP (2011) stipulates that it is important that the chosen KPIs are seen as meaningful and applicable to the specific barrier systems at the facility. Table 4.6 shows examples of KPIs proposed by OGP (2011). In Table 4.6, % refers to percentage and No. refers to Number.

Barrier/risk control system	**Example KPI (Tier 3)**	**Example KPI (Tier 4)**
Management and workforce engagement (MWE) on safety/ asset integrity	• % of manager inspections delegated to subordinates • % of safety meetings not fully attended by staff working that day • No. of barrier weaknesses, including unsafe conditions, identified from MWE	• % of manager inspections of work locations completed • Total hours spent on MWE activities by managers and by staff • % MWE suggestions implemented • Staff opinion/attitude survey outcomes on health of asset integrity/process safety barriers, including leadership, competence, safety culture and equipment design
Hazard identification and risk assessment (HIRA)	• No. of recommendations / actions unresolved by their due date • No. of actual or near-miss LOPC events where inadequate HIRA was a causal factor • No. of P&ID corrections and other actions identified during PHAs	• No. of planned HIRA completed on schedule • Average no. of hours per P&ID for conducting a) baseline PHAs b) PHA revalidations
Competence of personnel	• No. of actual or near-misses, LOPC events, plant trips, equipment damage linked to a) trainees b) lack of technical understanding c) lack of experience d) inadequate training e) absence of skills in team • No. of workers in each personnel category whose training is overdue • % time that asset integrity/process safety critical positions have gone unstaffed	• % personnel assessed to be i) partly, ii) fully, and iii) exceeding local competence criteria for all asset integrity/process safety critical roles in each personnel category • No. and outcome of periodic reviews to check accuracy of asset/process knowledge
Operational procedures	• No. of operational errors due to incorrect/ unclear procedures • No. of operational shortcuts identified by near misses and incidents • No. of PHA recommendations related to inadequate operating procedures	• % of procedures reviewed and updated versus plan

Barrier/risk control system	Example KPI (Tier 3)	Example KPI (Tier 4)
Inspection & maintenance	• No. of actual or near-miss LOPC events where inadequate inspection or maintenance • No. of non-routine and emergency maintenance work orders • No. of process leaks identified during operation or downtime • No. of temporary repairs or deferred maintenance items in service • % of safety-critical plant/equipment that performs to specification when tested was a causal factor	• % maintenance plan completed on time • % of planned preventative maintenance versus total maintenance (including unplanned)
Plant design	• No. of incidents or near-misses where errors in plant design are identified as a contributory cause	• No. of post-startup modifications required by Operations • No. of deviations from applicable codes and standards • % safety-critical equipment/systems fully in compliance with current design codes
Safety instrumentation and alarms (SIA)	• Total no. of SIA activations reported by operations • Total no. of SIA faults reported during tests • Alarms per hour	• Mean time between alarm activations and operator responses • No. of individual SIA tests versus schedule
Start-ups and shutdowns (S&S)	• No. of near-misses or incidents during S&S • No. of deferred start-ups and unplanned shutdowns	• % relevant personnel trained on S&S prior to commencing S&S • % relevant personnel present during S&S versus plan
Management of change (MOC)	• No. of actual or near-miss LOPC where inadequate MOC was a causal factor • % MOCs for which the drawings or procedures were not updated • No. of emergency or temporary MOCs	• No. of planned MOCs performed and time taken • % plant changes suitably risk assessed and approved before installation • Average time taken to fully implement a change once approved
Permit to work (PTW)	• % incidents/near misses during work covered by a PTW • % PTWs sampled which failed to identify all hazards or specify suitable controls	• No. of PTW issued • Average time per permit spent on writing, reviewing, and approving PTW
Contractor Management	• Asset integrity and general safety KPIs for contractor companies, average for all clients and when under contract to company • No. and % of open/unresolved contractor safety suggestions	• % required contractor training conducted on schedule • Frequency of, and % attendance during, contractor safety meetings • % of qualification audits/checks/ criteria met prior to entry
Emergency management	• No. of emergency response elements that are not fully functional when activated in a) a real emergency b) an emergency exercise	• No. of emergency exercises on schedule and total staff time involved • % of staff who have participated in an emergency exercise • No. of emergency equipment and shutdown devices tested versus schedule
Compliance with standards	• No. of compliance violations related to asset integrity/process safety	• % of existing standards reviewed as per schedule to ensure evergreen status

Table 4.6: Examples of risk control barriers and associated KPIs, based on excerpts from OGP (2011)

As stated in chapter 3.12.2, it should be established certain requirements to such indicators as those presented in Table 4.6. The KPIs presented in Table 4.6 incorporate most of the KPIs presented by Vinnem (2010). Vinnem (2010, p. 781) states that several of the proposed KPIs are "considered to have over-focused on the need to be able to measure, and far too little attention to the (…) criteria relating to intuitiveness, reflection of hazard mechanism, robustness to manipulation and validity for major hazard risk".

4.7 Barrier performance panel

Vinnem (2010, p. 782) describes how some operators have established a *barrier performance panel* that is "a system for periodic reporting and follow-up of the performance of major hazard barriers". Such a system may cover leading and lagging indicators, and the barrier panel is suggested to be updated every 3 or 6 months, "with a rolling 12 month average" (Vinnem, 2010, p. 782).

The barrier panel can present the status for each barrier element "in relation to the incidence rate of faults during testing", and can be related to the industry average (Vinnem, 2010, p. 782). In addition, the barrier panel can present trend "based on the last 12 months in relation to the previous 12 months period" (Vinnem, 2010, p. 782). Figure 4.3 show an example of such a barrier panel for installation Y.

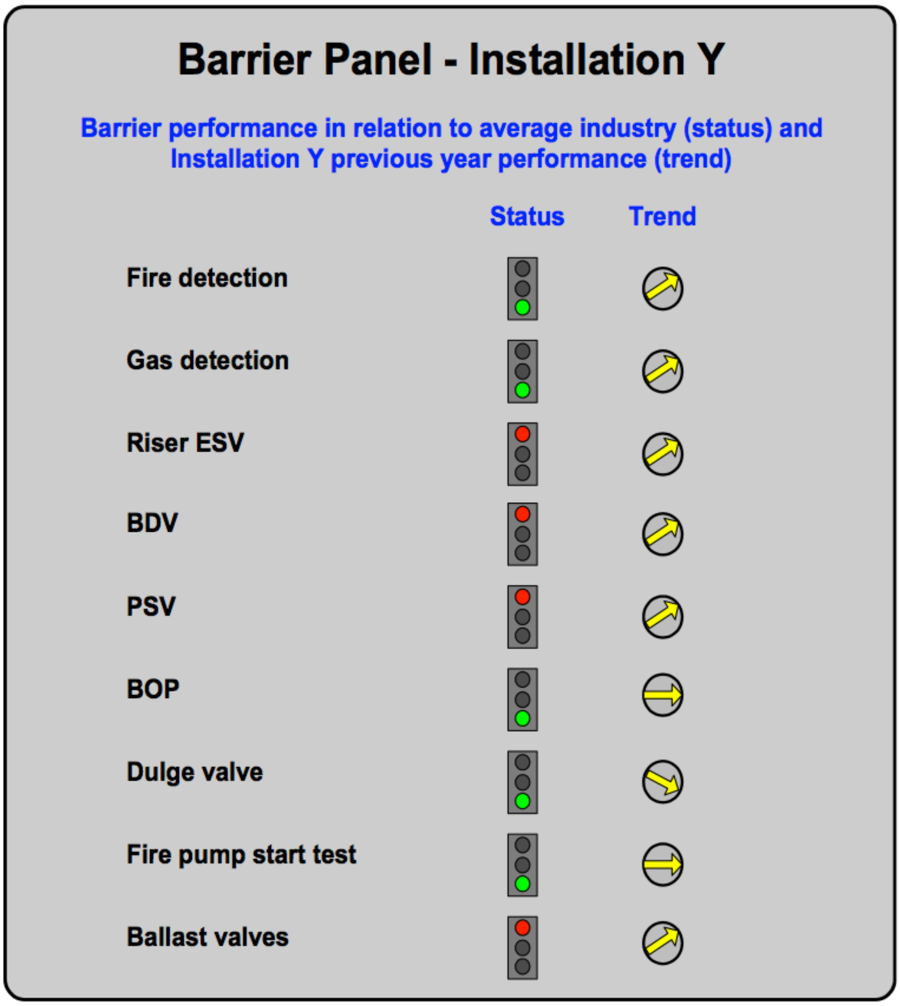


Figure 4.3: Example of a barrier panel for installation Y, Vinnem (2010)

4.8 Company specific methods, processes and tools

The following subchapters address company specific methods, processes and tools. TIMP, TTS and OTS are solutions used by the Norwegian energy company Statoil. There are also a number of companies that have solutions that are of great similarity to TTS (Fløtaker, 2013a). Furthermore, the tool used at Kårstø gas plant is addressed, and a common action pattern, or best practice, used by Statoil, as well as an overall risk indicator, is presented.

4.8.1 TTS

Statoil (2007) has, since 2001, yearly conducted extensive technical audits and verifications of their offshore installations. This has been done by the Technical Conditions Safety (TTS) audit approach, which is an approach for monitoring technical condition of safety barriers and equipment. Vinnem and Haugen (2012, p. 40) present an overview of the PSs in TTS, as shown in Table 4.7. These PSs are also used in TIMP.

PS no	PS title
1	Containment
2	Natural ventilation & HVAC
3	Gas detection
4	Emergency shutdown
5	Open drain
6	Ignition source control
7	Fire detection
8	Emergency depressurization, flare/vent system
9	Active fire protection
10	Passive fire protection
11	Emergency power and lightning
12	Process safety
13	PA, Alarm and communication system
14	Escape, evacuation and rescue
15	Layout design principles and explosion barriers
16	Offshore cranes
16B	Drilling hoisting systems
17	Well integrity
18	Ballast water and positioning keeping
19	Ship collision barriers
20	Structural integrity
22	Human machine interface & alarm management

Table 4.7: Overview of performance standards in TTS, based on Vinnem and Haugen (2012)

Vinnem et al. (2007) explain that there are established a set of PRs for each PS. It is against these requirements the condition of the system is measured. Furthermore, the systems are then rated as in Table 4.8.

Rating	Description of condition
A	Condition is significantly better than the reference level (PR)
B	Condition is in accordance with the reference level (PR)
C	Conditions satisfactory, but does not fully comply with the reference level (PR)
D	Condition is acceptable and within the statutory regulations' minimum intended safety level, but deviates significantly from the reference level (PR)
E	Condition with significant deficiencies as compared with "D"
F	Condition is unacceptable

Table 4.8: Rating in TTS of condition of systems, based on Vinnem et al. (2007)

The structure of TTS and OTS is shown in chapter 4.8.2 to show the relationship between TTS and OTS. Furthermore, the following subchapter, chapter 4.8.1.1, somewhat illustrates the process applied in the TTS approach.

4.8.1.1 Overall risk indicator

Thomassen and Sørum (2002, p. 1) describe a method that can be applied "to map and monitor the technical safety level on (…) offshore platforms and land based facilities based on the status of safety critical elements, safety barriers, and their intended function in major accident prevention". Thomassen and Sørum (2002) have based the method on ISO 13702 (1999) which is the standard of "Petroleum and natural gas industries - Control and mitigation of fires and explosions on offshore production installations - Requirements and guidelines" and IEC 61508 (1998) which is the standard of "Functional safety of electrical / electronic / programmable electronic safety-related systems".

The basic idea behind the method is that the installation's safety condition is "measured by the status of the safety barriers relative to defined requirements and best practice" (Thomassen and Sørum, 2002, p. 2). The defined requirements are stipulated through QRA, and by combining "the status of each system forming the barrier with their importance in preventing or mitigating the identified hazard, the risk level may be indicated" (Thomassen and Sørum, 2002, p. 2). Furthermore, Thomassen and Sørum (2002) state that a reference has to be defined which the technical safety condition is to be measured against. Thus, PSs need to be established that describe (Thomassen and Sørum, 2002, p. 2):

- The role of safety systems as a barrier in the accidental scenario.
- List main requirements and best practice for each system.

Furthermore, there are nine steps to the method that are to be applied for each installation (Thomassen and Sørum, 2002, p. 2):

1. *Scenarios*: Establish scenarios to be considered for the relevant installation / plant.
2. *Barriers*: For each scenario, establish the chain of events showing the main barriers preventing a hazardous situation to occur or to develop. Identify the systems that are included in each barrier.

3. *System role*: For each system, describe the system role as a risk reducing measure.
4. *Performance standards*: Supplement the general performance standards with relevant scenario dependent performance standards.
5. *Installation review*: For each system, examine the system's performance against the established performance standard.
6. *Score*: For each system and for each requirement in the performance standard, score the actual performance for the given factor on a predefined scale.
7. *System aggregation*: For each system, aggregate the score of each standard based on the requirement's given weight for that system.
8. *Installation aggregation*: Based on the systems total score, describe and estimate the system's actual risk reducing effect compared to the effect assumed in the risk analysis.
9. *Risk indicators*: For each installation or plant, indicate the total risk level and how it compares with the total risk level estimated in the risk analysis.

Furthermore, each requirement is given a weight due to the difference of importance of the identified requirements, and to be able to reflect the level of risk. Such weight factors are based on expert judgement and risk analysis. Moreover,

> "within a system the weight reflect how important the requirement is for system function in terms of functionality, integrity (reliability of availability) or vulnerability (survivability in an accident situation). The systems are then weighted based on their importance as barrier for the risk of the installation" (Thomassen and Sørum, 2002, p. 2).

The PSs defined for the method are listed in Table 4.9

PS no	PS title
1	Containment
2	Natural Ventilation and HVAC
3	Gas Detection System
4	Emergency Shut Down (ESD) System
5	Open Drain System
6	Ignition Source Control
7	Fire Detection System
8	Blowdown and Flare / Vent System
9	Active Fire Protection
10	Passive Fire Protection
11	Emergency Power and Lightning
12	Process safety (PSD/PSV etc.)
13	PA, Alarm and Emergency Communication
14	Escape and Evacuation
15	Explosion Barriers
16	Offshore Cranes
17	Drilling and Well Intervention
18	Ballast Water and Positioning Keeping
19	Ship Collision

Table 4.9: Performance standards used in mapping and monitoring technical safety level, based on Thomassen and Sørum (2002)

For each PS a set of PRs are established and grouped as follows (Thomassen and Sørum, 2002, p. 3):

- Function (F); essential duties that the system is expected to perform as a safety barrier.
- Integrity (I); reliability and availability requirements to the system during normal operating environments.
- Survivability (S); ability to perform as barrier exposed to accidental loads
- Management (M); documentation, deviation handling, management of changes, human factors and competence.

As step 5 states, when PSs are established, a review of the installation is then to be performed. The examination activities to be performed are (Thomassen and Sørum, 2002, p. 3):

- Documentation and design review
- Interviews
- Visual inspection
- Test

Based on the examination activities, data is then aggregated and quantified as to show the status of the installation and its systems. Each PR is given a grade as shown in Table 4.10.

Rating	Description of safety level	Numerical value
A	Condition is significantly better than the reference level (PR)	3
B	Condition is in accordance with the reference level (PR)	2
C	Conditions satisfactory, but does not fully comply with the reference level (PR)	1
D	Condition is acceptable and within the statutory regulations´ minimum intended safety level, but deviates significantly from the reference level (PR)	0
E	Condition with significant deficiencies as compared with "D"	-2
F	Condition is unacceptable	-5

Table 4.10: Definition of grades for how the system meets the performance requirements, based on Thomassen and Sørum (2002)

The result of each PS can then be presented. This is illustrated in Figure 4.4, where the "length of each bar corresponds to the fraction of PRs that are given the grade" (Thomassen and Sørum, 2002, p. 5).

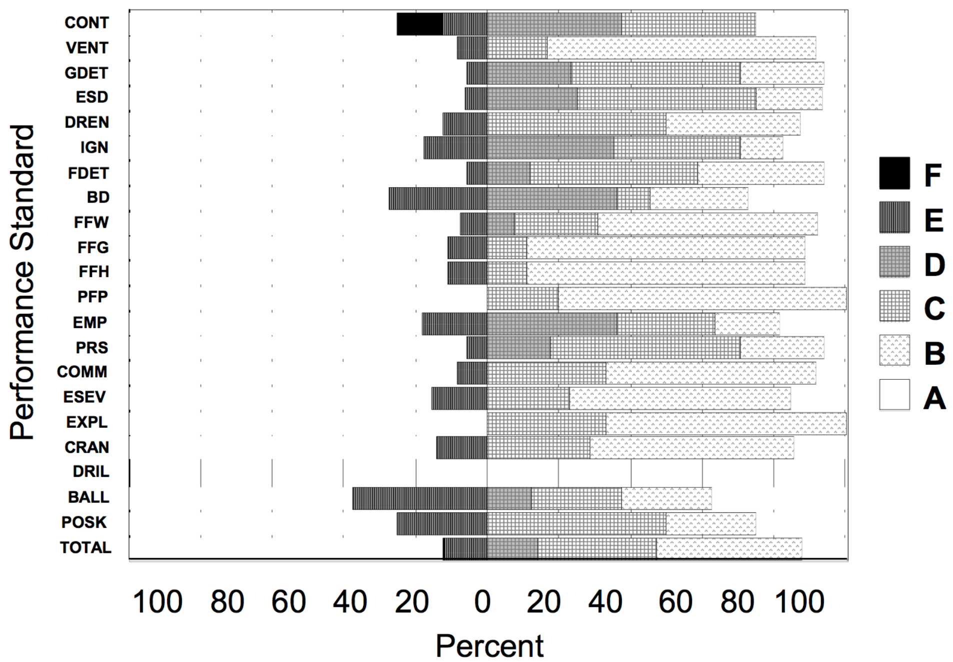


Figure 4.4: Example of result presentation for one installation, Thomassen and Sørum (2002)

Moreover, by applying such a method, comparisons can be made between installations as shown in Figure 4.5. Figure 4.5 shows the grades for gas detection given for each installation on the y-axis.

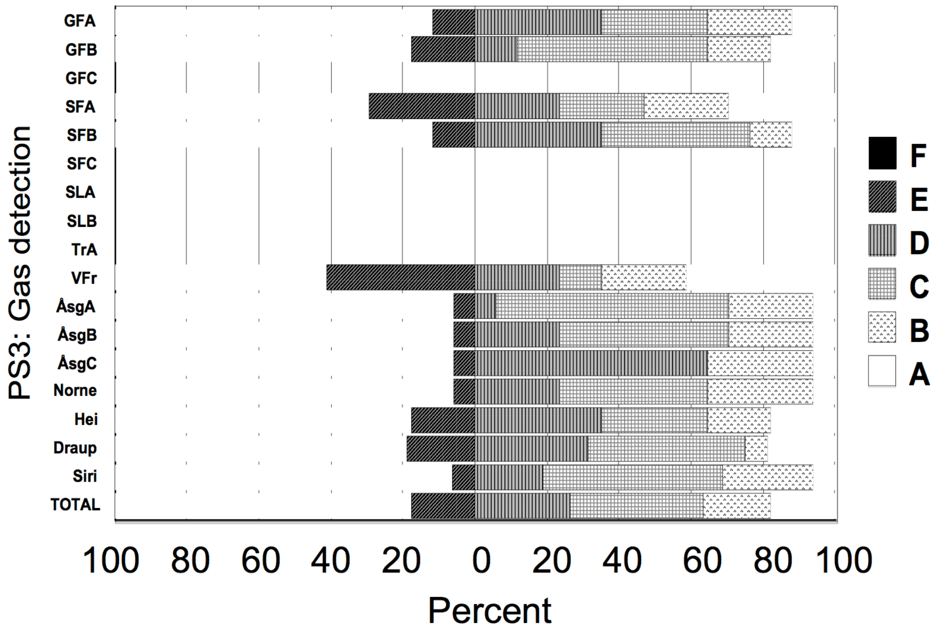


Figure 4.5: Example of comparison between installations, here grades for gas detection, Thomassen and Sørum (2002)

When grades are given for each PR, scoring of overall performance can be performed by aggregating the data, and giving a weight to the safety system grades based on their significance for risk. Thomassen and Sørum (2002, p. 5) state further that the result "form an indicator for the installation as a total", that can be used to monitor the level of risk.

As step 9, mentioned prior, states, the indicated total risk level is to be compared "with the total risk level estimated in the risk analysis" (Thomassen and Sørum, 2002, p. 2). This method thus describes a way of considering the total risk of the platform against acceptance criteria for risk.

Figure 4.6 shows an example of the development over time of such an indicator. The figure shows the "overall major hazard risk indicator for Frigg Central Complex" (Vinnem, 2011).

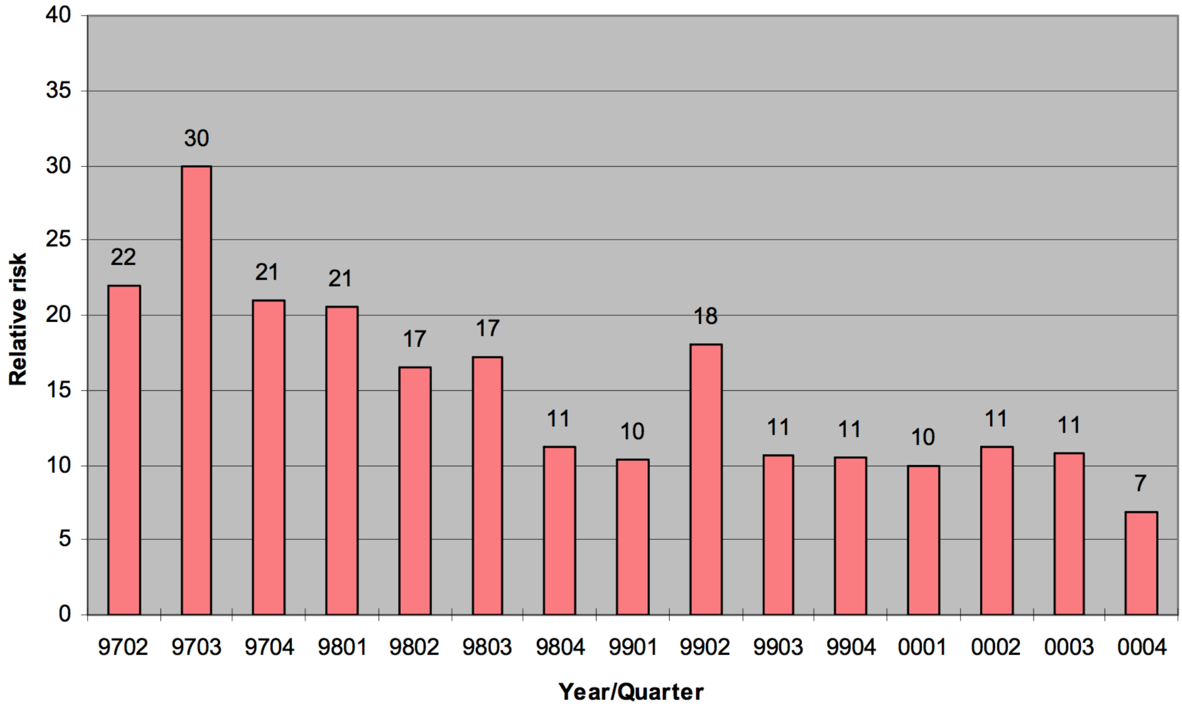


Figure 4.6: Overall major hazard risk indicator for Frigg Central Complex, Vinnem (2011)

4.8.2 OTS

Operational Conditions Safety (OTS) audit is another audit approach employed by Statoil (2007). Like the TTS approach, the OTS approach is also a way of measuring and verifying condition of safety barriers, but instead of measuring technical conditions it measures the condition of operational RIFs. Moreover, the OTS approach applies the same rating system, A to F, as the one used in TTS. Before testing in 2007, the RIFs shown in Table 4.11 were included in the approach (Statoil, 2007).

RIF no	RIF title
1	Work practice
2	Competence
3	Procedures and documentation
4	Communication
5	Management
6	Management of work
7	Physical work environment
8	Management of changes
9	Working hours factors

Table 4.11: Risk Influencing Factors monitored in OTS, based on Statoil (2007)

The structure of OTS and TTS is shown in Figure 4.7.

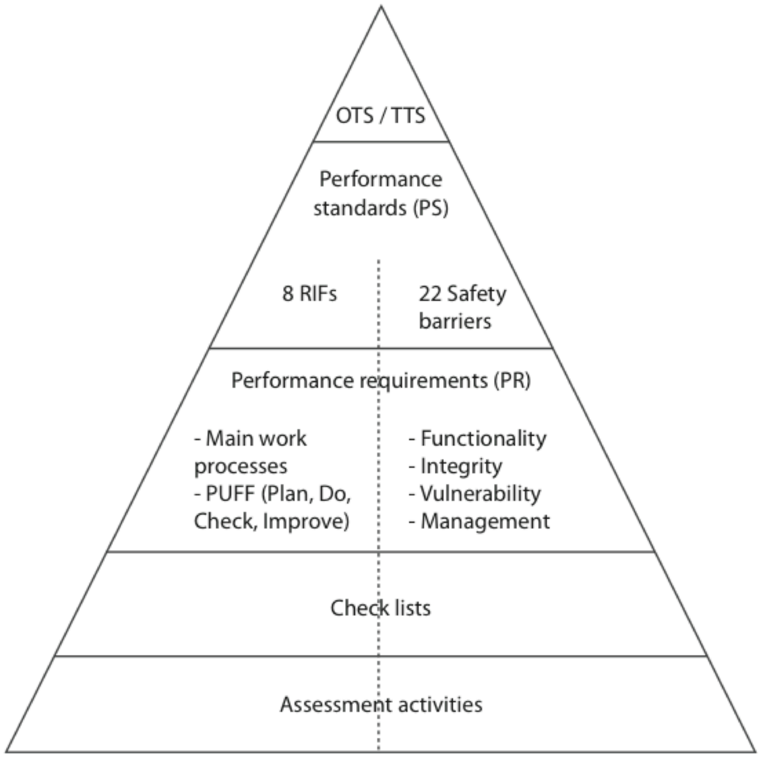


Figure 4.7: Structure of TTS and OTS, based on Vinnem (2009)

4.8.3 TIMP

Technical Integrity Management Portal (TIMP) is Statoil's solution to technical integrity management (Lunde, 2012). TIMP builds on the competence and the expert judgement of its users, along with input from other tools in use by the company, to assess and continuously monitor the technical condition on equipment, system and barrier level at their facilities both offshore and onshore. This is illustrated in Figure 4.8 below.

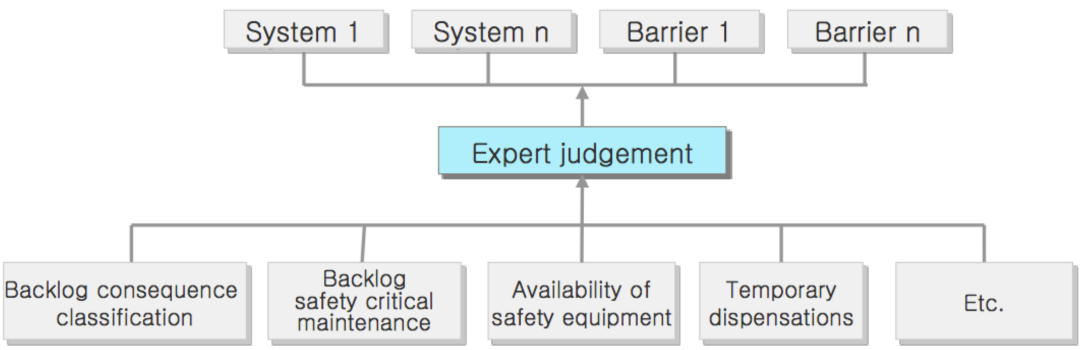


Figure 4.8: Assessment of technical condition in TIMP, Lunde (2012)

According to DNV, TIMP gathers information from the following other tools in use by the company (Fløtaker, 2013a):

- The maintenance and administration system, SAP
- The dispensation system, DISP
- The HSE incident reporting tool, SYNERGI
- The audit management and reporting system, SAMS, which contain all TTS actions

SAP and SYNERGI are examples of commercially available software. These types of tools were addressed in chapter 3.11. In addition to the above-mentioned tools, QRA and technical information have to be used to assess technical condition (Lunde, 2012).

The PSs in use in TIMP are the same as those in use in TTS that are presented in chapter 4.8.1. These PSs are assessed and given a rating between B and F as shown in Table 4.12 (Fløtaker, 2013b). Moreover, the ratings correspond to a colour coding to allow for intuitiveness, where green is considered as "best", as also shown in Table 4.12.

Rating	Description of condition	Colour coding
B	Condition is in accordance with the reference level (PR)	(green)
C	Conditions satisfactory, but does not fully comply with the reference level (PR)	(light green)
D	Condition is acceptable and within the statutory regulations' minimum intended safety level, but deviates significantly from the reference level (PR)	(yellow)
E	Condition with significant deficiencies as compared with "D"	(orange)
F	Condition is unacceptable	(red)

Table 4.12: Rating in TIMP of condition of systems, based on Vinnem et al. (2007), Fløtaker (2013b) and Lunde (2012)

Fløtaker (2013a) states that the reason behind the rating ´A´ not being used is that conditions significantly better than the reference level (PR) seldom occurs. The results of these ratings are then presented in what resembles a typical bow-tie diagram, as shown in Figure 4.9.

Figure 4.9: Presentation of PS rating in TIMP, Lunde (2012)

As can be seen in Figure 4.9, TIMP also expresses the development of the rating of a PS by displaying an arrow behind each PS. By giving a weight based on expert judgement to the barriers, TIMP is able to indicate plant status and trend over time. Figure 4.10 shows the technical integrity KPI, "TI-indicator", and trend over time TIMP provides.

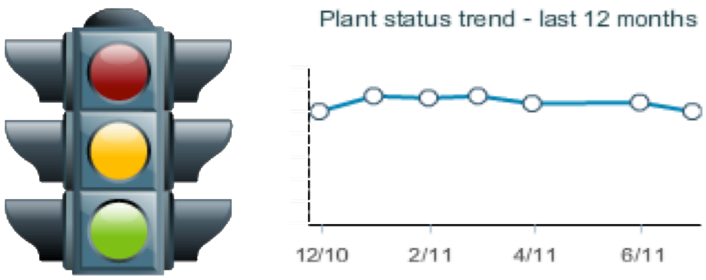


Figure 4.10: Technical integrity KPI and trend from TIMP, based on Lunde (2012)

4.8.4 The risk management tool used at Kårstø gas plant

Kårstø gas plant is a land-based facility in Nord-Rogaland, Norway (Gassco, 2013). Gassco operates the process plant at Kårstø, and Statoil provides the technical service. The Kårstø plant separates, amongst other, HC that comes from the Stapine and Åsgard Transport pipelines.

Kårstø gas plant is exposed to increasing project activity and extensive construction in periods (Statoil, 2011). Comprehensive modifications including upgrade of technical facilities and expansion of the processing capacity simultaneously with full production, result in increased major accident risk (Statoil, 2011). To manage such risk, QRA is performed in advance to calculate the risk per fire area, the leak frequency, ignition probabilities and exposed personnel. The risk is expressed as fatal accident rate (FAR) per fire area and for the facility in total during normal operation (Statoil, 2011). Rausand (2011, p. 91) defines FAR as:

> *FAR:* "The expected number of fatalities in a defined population per 100 million hours of exposure"

Furthermore, Rausand (2011, p. 91) expresses FAR as:

$$\text{FAR} = \frac{\text{expected no. of fatalities}}{\text{no. of hours exposed to risk}} \cdot 10^8$$

To manage risk during periods of high activity, like simultaneous development and operations, the solution was found to be a risk management tool that is easy to use and that estimates and indicates the risk to personnel. Figure 4.11 shows a simplified model of the risk model applied.

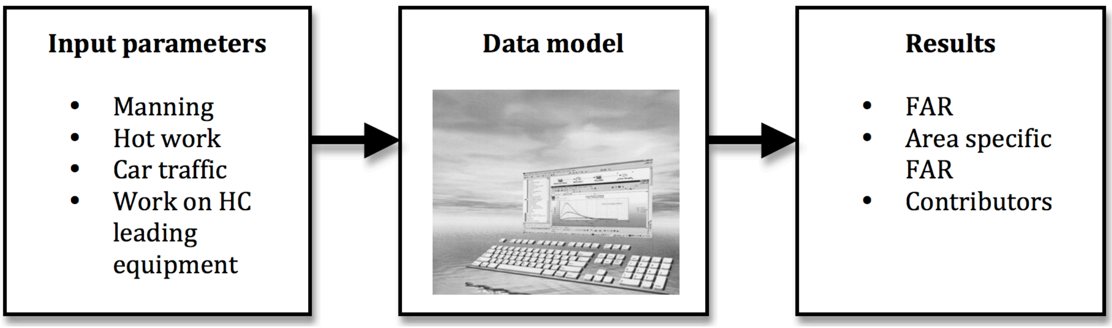


Figure 4.11: Simplified risk model for Kårstø gas plant, based on Statoil (2011)

As can be seen from Figure 4.11, the tool focuses on the type of activity and the number of activities. Moreover, Figure 4.12 shows the result from the tool when applied to a three months long operation plan.

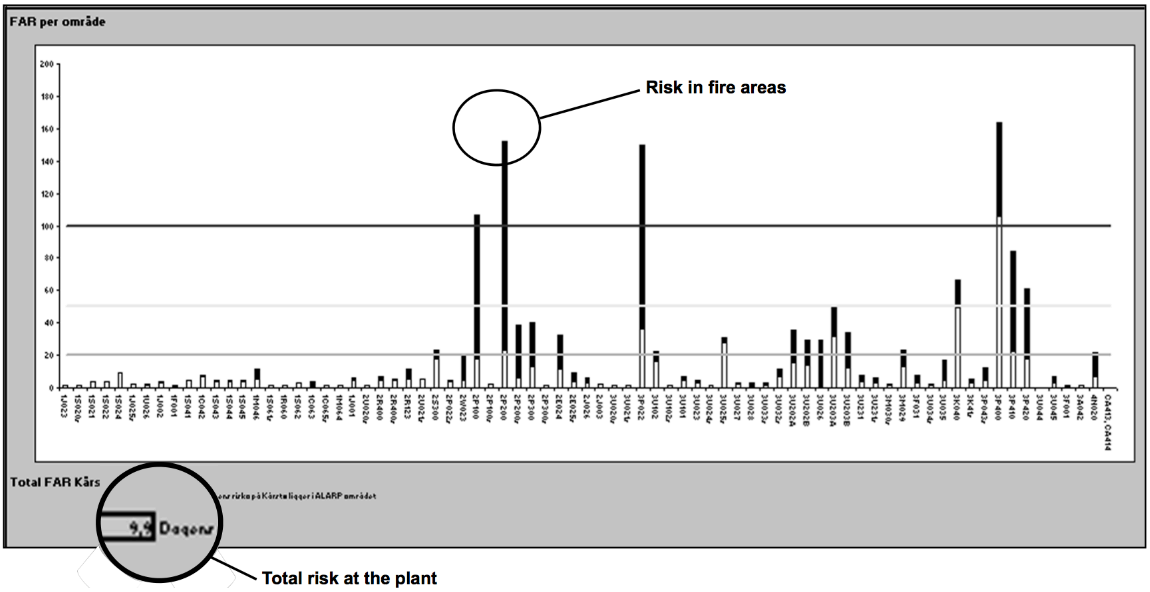


Figure 4.12: Resulting FAR in a three months long operation plan, Statoil (2011)

Furthermore, the total risk of the plant, the estimated FAR, can then be considered against tolerance limits for risk. Vinnem and Haugen (2012, p. 35) state that:

> There are tolerance limits defined for stable operation and simultaneous operation and project (extensions) work, for different averaging periods, e.g. for 1 year, 1 month, 1 week and 1 day.
>
> There are values expressed for plant average and per fire area. The highest value for 1 day duration in a separate fire area with simultaneous operation and project work is a FAR value equal to 200.

4.8.5 A-standard

The A-standard is a common action pattern, a best practice, used by Statoil, and describes how Statoil "prepare, perform and evaluate (…) work tasks" (Statoil, 2013b, p. 3). The following steps are to be undertaken according to the A-standard:

Step 1 - Activity: "Understanding the task and identifying risk" (Statoil, 2013, p. 15)

Step 2 - Requirements:	Obtain “requirements (…) that govern the task” (Statoil, 2013, p. 15)
Step 3 - Method:	Obtain “procedures that govern the task” (Statoil, 2013, p. 15)
Step 4 – Team assessment:	“the final quality check performed by individuals and teams” (Statoil, 2013, p. 15)
Step 5 – Execution:	Undertaking the task including “continues risk evaluation” (Statoil, 2013, p. 15)

Risk is thus managed “by complying with requirements and methods and by adding (…) own knowledge and expertise” (Statoil, 2013, p. 19) as stipulated in step 2, 3 and 4. In addition, learning and improvement is achieved by evaluating the results after the task is executed (Statoil, 2013).

5 DECISION-MAKING AND SUPPORT RELATED TO PLANNING OF ACTIVITIES ON THE INSTALLATION

5.1 Introduction

The purpose of the risk control tool, outlined in chapter 3, includes decision support in situations where the decision-maker(s) have to decide whether activities can or cannot be performed based on information on the state of safety barriers, characteristics of the activity, the risk increase due to activities and relevant indicators and other information that is suitable for helping the decision-maker make an educated decision. In order for a decision to be made, certain criteria have to be established that stipulate the bounds for which the decision should be made upon. The decision support, as such, is thus reliable information presented through a robust information surface, an assessment of the risk increase due to the activity, and decision-making criteria where practicable. Figure 5.1 shows the basic elements of the decision sequence.

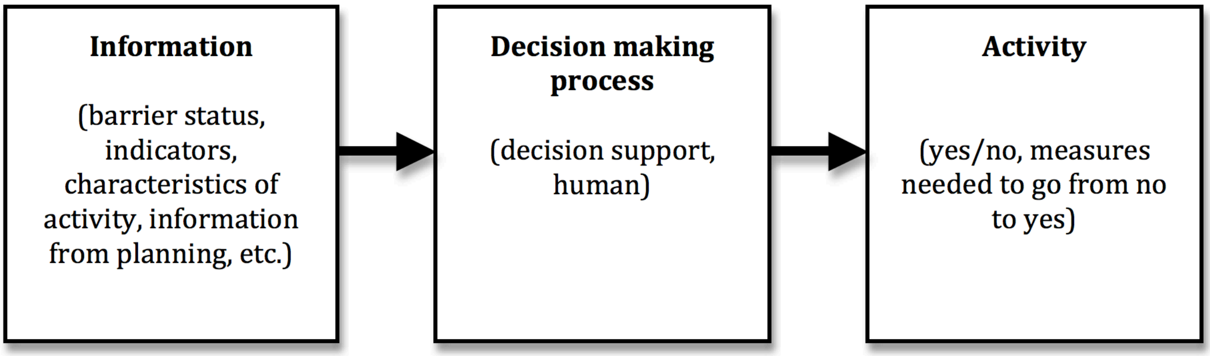


Figure 5.1: Basic elements of decision sequence, partly based on Sklet (2006)

The following subchapters present how decision-making support can be provided related to planning of activities on the installation, including decision-making criteria for the activities that are not permitted based on, amongst other, information on the state of the safety barriers. In addition, an example utilising the decision support is presented.

5.2 Selection of how decision-making criteria is to be established

For this thesis, it has been considered the possibility of some possible ways of establishing decision support and decision criteria. One possibility could be to establish one or more decision matrices. Such a matrix would have to take a tremendous amount of information and factors into account. Theoretically, it could be possible to establish such a matrix, but nevertheless, it would not be able to cover all the needed factors, as one activity seldom is exactly like another. Sklet (2013b) states that the idea of such a decision matrix is farfetched, and that there are to many factors to consider. A decision matrix could also, as found in chapter 2.10, underestimate what the professional judgement of the platform manager, the operational management or senior personnel can contribute to safety.

A (or one) general decision criterion solely based on the condition of the safety barriers/-systems is also considered as inadequate when deciding whether or not an activity can be performed. To solely base the decision on the state of the safety barriers would exclude factors such as the influence of simultaneous activities etc. There are also too many cases where this would not work (Sklet, 2013b).

Based on the assessment above, it is considered to be more useful to present a range of criteria to the decision-maker(s), that need to be fulfilled if the activity is to be performed.

5.3 Establishing a basis for decision-making criteria

The following list contains a proposed, but not necessarily limited to, range of factors that criteria can build upon:

- Barrier status of technical safety barriers/-systems (Sklet, 2013a).
- Factors related to organisational safety barriers (PSAN, 2011b):
  - Competence and experience
  - Communication
  - Documentation
  - Work load
  - Responsibility and roles
  - Resources, capacity
  - Work practice
- The need for and possibility of replacement barriers (Sklet, 2013a)
  - If not required barriers are in place
  - If work is to be performed on a safety barrier

- The activity level on the deck, and especially in the area where the intended activity is to be performed (Sklet, 2013a). The activity level can for instance be the number of people in an area, the number of activities including hot work, or the number of activities in total.
- Whether or not the activity is in conflict with other activities with / on the same equipment / system (Fløtaker, 2013a).
- Whether or not the activity is in conflict with other simultaneous activities on the installation, deck or area[4].
- Whether information found in dispensations states any limiting factors that may lead to the activity not being performed, e.g. deviations related to safety, control or barrier systems (Fløtaker, 2013a).
- Factors such as weather and wind.
- Operational factors such as pressure, time and temperature (Sklet, 2013b) and operational requirements such as "minimum requirements for equipment, e.g. must have one pump running and one on-line spare, or must not run without gas detection in place" (Hayes, 2012, p. 425).
- Preconditions and assumptions used in QRA (Fløtaker, 2013b).
- Preconditions stipulated and risk considerations performed during the onshore planning of the activity (Sklet, 2013b).
- Risk level due to activity is within acceptable region. Different types of activities involve different amount of risk, e.g. painting is considered less "risky" than hot work (Sklet, 2013b).
- All indicators that are important and relevant for the purpose and that can be controlled / managed upon (Fløtaker, 2013b). Examples of indicators are given in chapter 4.

The risk level due to activity, as mentioned above, can be included if the risk control tool incorporates a function for calculating the overall risk of the platform that can be considered against tolerance limits for risk. This function could, for instance, be similar to the one implemented at Kårstø gas plant, which is reviewed in chapter 4.8.4. If such a function is to

[4] A decision criterion used by the Norwegian operator Statoil is a simultaneity matrix that states the type of activities that can or cannot be performed simultaneously, e.g. hot work is not to be performed simultaneously with work being performed on a gas system (Sklet, 2013a).

be incorporated into a tool for an offshore installation, the function should take into it the most important offshore indicators (Fløtaker, 2013b). Fløtaker (2013b) states that this is a good solution, but that it can be hard to incorporate such a function.

5.4 Examples of decision-making criteria

Each factor presented to the decision-maker should be assessed using decision-making criteria and/or the decision-maker's knowledge and judgement. The following table, Table 5.1, contains examples of decision-making criteria that are proposed to help the decision-maker. For the sake of the example of a decision-making scenario, presented in chapter 5.7, the criteria are numbered in the table.

Criteria related to	Criteria	No.
Barriers	Requirements of and to needed safety barriers' function fulfilled	1
	Requirements of temporary replacement barriers fulfilled	2
	Are the temporary replacement barriers "good enough"?	3
Activity	Not in conflict with a set maximum activity level	4
	Not in conflict with simultaneous activities on / with the same equipment / system	5
	Not in conflict with simultaneous activities on the installation, deck or area	6
	Not in conflict with established max. risk level	7
Weather	Within restrictions related to weather window	8
Dispensations	Not in conflict with information in dispensations	9
QRA, operational factors and onshore planning	Not in conflict with operational factors or requirements, like max. pressure, temperature and time	10
	Not in conflict with operating limits or preconditions used in QRA	11
	Not in conflict with preconditions stipulated and risk considerations performed during the onshore planning of activities	12

Table 5.1: Examples of decision-making criteria presented as decision support related to performing activities on the installation, based on Fløtaker (2013a), Fløtaker (2013b), Sklet (2013b) and Ertsaas (2013)

In relation to decision-making criteria utilising the status of safety barriers when deciding whether an activity can or cannot be performed, it can be seen in Table 5.1 that such criteria are (Sklet, 2013b):

- Is the requirement of and to needed safety barriers' function fulfilled?
- If not, can temporary replacement barriers be provided?
- If yes, are the temporary replacement barriers "good enough"?

This means that if requirements of and to needed safety barriers' function cannot be fulfilled, temporary replacement barriers that are "good enough" need to be established if the activity is to be performed. This, in turn, means that if requirements of and to needed safety barriers' function can in fact be fulfilled, criteria relating to temporary replacement barriers need not be fulfilled. These criteria correspond well with the lessons learned in the case study performed by Hayes (2012), as presented in chapter 2.10.

Furthermore, there are certain requirements that must be met regarding temporary replacement barriers in need of being "good enough". PSAN states that it is important that temporary replacement barriers meet functional requirements as stipulated in regulations (Dahle, 2013). This, in turn, means that a temporary replacement barrier must provide the same function or contribution as what was intended with the barrier it replaces (Dahle, 2013). Moreover, Sklet (2013c) states that when applying temporary replacement barriers, it must be documented that this help ensure safety or that the risk is not increased. Sklet (2013c) states further that this is not an easy task, and that it may be necessary in some cases to carry out own risk assessments of conditions to show that the risk is acceptable. However, this is often substantiated with simple qualitative descriptions of the measure (Sklet, 2013c).

Statoil has its own system where it can be applied for dispensations if the requirements to safety barriers are to be waived. In this system it must be explained why the requirements cannot be followed, described compensatory measures and substantiated that the risk is still acceptable (Sklet, 2013c). There are also routines for who can accept these applications, both "in the line" and the relevant specialist environments, to get a form of independence into account (Sklet, 2013c). PSAN states that temporary replacement barriers are not always appropriate or practical considering other simultaneous activities or the production in itself, but PSAN`s general opinion is that the operators on the NCS do not find this to be a great challenge (Dahle, 2013). If this was in fact a great challenge, PSAN would have it as one of its main priorities (Dahle, 2013).

5.5 Compliance with decision-making criteria

As can be seen from Figure 5.1, *human* is included in the decision-making process. This is to account for the fact that the tool is to be used by a human being during decision-making related to activities on the installation. This is also to account for the fact that some factors, that the decision is to be based upon, are strictly not only "within" or "not within" the limits of criteria. Thus, some factors are likely to be assessed utilising the decision-maker(s) knowledge and judgement.

When assessing the compliance with decision-making criteria, as for instance those presented in Table 5.1, some criteria could be answered with a simple "fulfilled" or "not fulfilled", while others will need an assessment of whether the criteria can be fulfilled and to what degree. Furthermore, by differentiating the degree of fulfilment using colour coordination, the tool can provide intuitive support. This is illustrated in Table 5.2 below.

Rating	Colour	Description of rating
	Green	Satisfactory compliance with decision criterion
	Yellow	Deficient compliance with decision criterion
	Red	Unacceptable compliance with decision criterion

Table 5.2: Example of rating of degree of compliance with decision criteria, partly based on Lunde (2012) and Vinnem et al. (2007)

Using the rating system proposed in Table 5.2, criterion can then be assessed either as illustrated in Figure 5.2 or Figure 5.3.

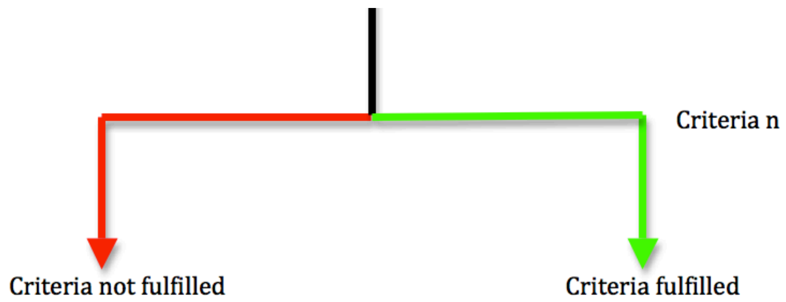


Figure 5.2: Degree of compliance with criteria, fulfilled or not fulfilled

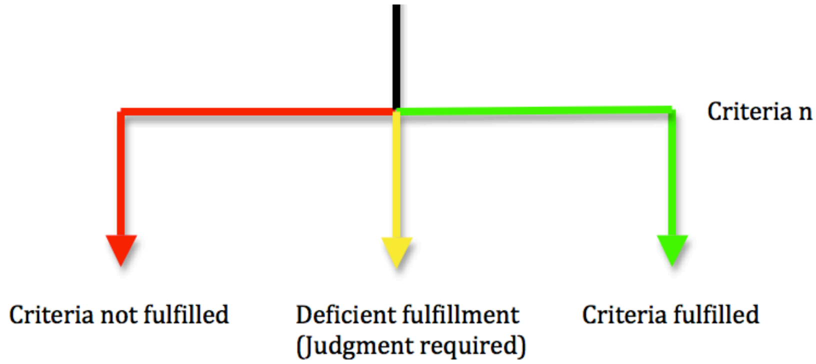


Figure 5.3: Degree of compliance with criteria, including deficient fulfilment

The decision-maker is to judge whether or not the requirements of and to needed safety barriers' function is fulfilled. With regards to technical safety barriers, such information can for instance be found in a barrier performance panel as shown in chapter 4.7. Regarding organisational barrier elements, information could for instance, as discussed in chapter 3.11.2, come from operational safety audits. Information can for instance also come from the platform manager's knowledge or the WP and/or a SJA. When the decision-maker is to assess the compliance with the criteria, he/she should stepwise be able to access the information needed to set the rating of compliance.

As stated in chapter 2.10, Hayes (2011, p. 431) states that the platform manager would limit "activities to within the limits of the remaining barriers" if not temporary replacement barriers could be provided for the impaired barriers. This, in turn, means that when the platform manager is to decide whether or not the activity can be performed, he/she must consider which barriers that are of great importance during the specific activity. This is a judgement call the platform manager has to make (Fløtaker, 2013a). Figure 5.4 shows an example of how the colour coordinated degree of compliance, found in Table 5.2, could be applied to decision-making criteria related to safety barriers.

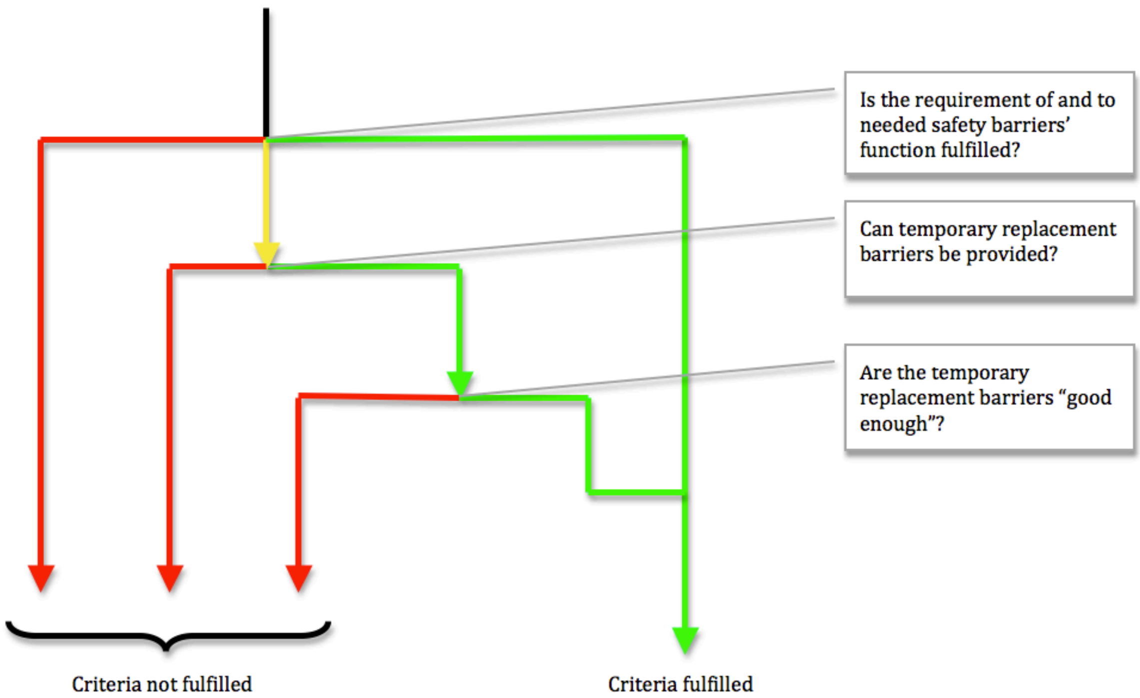


Figure 5.4: Compliance with decision-making criteria related to safety barriers, partly based on Fløtaker (2013b) and Sklet (2013b)

First, if it is clear that the requirement of and to needed safety barriers' function cannot be fulfilled, e.g. when for instance a barrier performance panel show that too many barriers have reduced performance for the task to be undertaken, criteria related to safety barriers' function can be rated as *not fulfilled* (red arrow in Figure 5.4). On the other hand, if it is clear that the requirement of and to needed safety barriers' function is fulfilled, the criteria related to safety barriers' function can be rated as *fulfilled* (green arrow in Figure 5.4). The third option, the yellow arrow in Figure 5.4, illustrates deficient compliance with the requirements of and to needed safety barriers' function. This option can be chosen for instance when:

- work is to be performed on a safety barrier/-system, resulting in a safety barrier/-system being for instance bypassed or disconnected.
- a safety barrier/-system has to be coupled out for the activity to be performed.
- a limited number of safety barriers, in for instance the barrier performance panel, show a reduced performance.

Such situations require assessment of whether or not temporary replacement barriers can be provided, as illustrated in Figure 5.4. Moreover, further assessment and judgement upon whether or not temporary replacement barriers are "good enough" is needed. Radio contact, fireguards, portable gas detectors connected to the control room and additional amount of personnel performing the activity are all examples of such temporary safety barriers (Sklet, 2013b). In addition, if work is to be performed on a safety barrier and it has to be bypassed or disconnected, certain considerations need to be made regarding the implication of this upon other activities, even though temporary replacement barriers can be established. Temporary replacement barriers classified as "good enough" for one activity may simultaneously not be "good enough" for other simultaneous activities. The same goes for other activities that require disconnection of safety barriers. If temporary replacement barriers are in fact "good enough", the result of criteria related to safety barriers is "*criteria fulfilled*".

5.6 Making the decision

When a final decision is to be made, the decision-maker can be presented with the factors that are classified as being of *deficient compliance*, i.e. all the factors that are given a yellow "light". As stipulated earlier in this chapter, it is not sufficient to simply base all decisions of whether or not to perform an activity on the basis of the status of the safety barriers. The status of the safety barriers is indeed an important factor when the decision is to be made, but there are other contributing factors that should be considered when making the decision. In addition, several yellow "lights" should in total, by themselves, point to the activity not being performed. It could also be argued that as little as one yellow "light" would point to the activity not being performed (Fløtaker, 2013b).

The final decision on whether or not the activity is to be performed is now in the hands of the decision-maker and his/her knowledge and professional judgement. The final decision should then be documented including the reasoning behind the decision.

5.7 Example of a decision-making scenario on the installation

The following is an example of a decision-making scenario utilising the decision support outlined in this chapter. Furthermore, the following decision-making scenario is an example of a scenario where the platform manager has to, amongst other, assess the possibility and quality of temporary replacement barriers.

Decision in need of support: Can personnel perform hot work on equipment / system (X) in the process area (Y) on deck (Z) between A and B o'clock? The hot work is not on a safety barrier.

Comments: Hot work is an activity associated with temporary increase of risk as stated by NORSOK Z-013 (2010). Ertsaas (2013) states that when the high-risk activity *hot work* is to be performed, the status of the safety barriers/-systems is essential to be known and verified. In addition, such an activity may require the disconnection of barriers like fire detection systems (Ertsaas, 2013). Such a disconnection requires that temporary replacement barriers as for instance radio contact and fireguards be established, which in turn requires additional amount of personnel for performing the activity (Sklet, 2013b). Execution of hot work can in a worst-case scenario result in a major accident, and the decision-making process related to such an activity should thus not be taken lightly.

Decision-making criteria: When the decision is to be made, the examples of criteria proposed in chapter 5.4 can be utilised.

Rating the compliance with decision criteria: The following table, Table 5.3, is an example showing the possible information presented to the platform manager as well as how the platform manager can possibly rate the compliance with the criteria.

Criteria related to	Criterion No.	Given information / Assessment	Rated compliance
Barriers	1	- Barrier panel shows green lights for all technical safety barriers/-systems. - Consideration of organisational barriers shows no discrepancies. - Fire detection system needs to be disconnected.	
	2	Radio contact and fireguards can be established.	
	3	The platform manager assess the temporary measures to be "good enough".	
Activity	4	The maximum activity level in the area (Y) is breached with one activity within the time frame.	
	5	No other work is being or is to be performed on equipment (X) within the time frame.	
	6	The hot work is not in conflict with other simultaneous activities in the time frame.	
	7	Performing the activity results in a high risk level mainly due to the risk increase of hot work but also due to a high activity level in the same time frame. Max risk level is however not reached.	
Weather	8	The forecast for wind condition shows an increase in wind speed to directly above the limit of the weather window during the time frame of the activity.	
Dispensations	9	Dispensations state no limiting factors.	
QRA, operational factors and onshore planning	10	Assessment shows no conflict with operational factors.	
	11	Assessment shows no conflict with operational limits used in QRA.	
	12	Assessment shows no conflict with preconditions stipulated and risk considerations performed during the onshore planning of activities.	

Table 5.3: Examples of given information and rating of compliance with decision-making criteria in a decision-making scenario

Making the decision: The platform manager needs to review the implications from criteria rated as *Deficient compliance with decision criterion* (yellow "lights") when deciding whether or not the hot work can be performed. The fact that the fire detection system has to be disconnected simultaneously as there is high activity level in the process area and a worsening weather condition should provide the platform manager with enough incentive to make a decision. The final decision on whether or not the activity can be performed is then taken and documented.

Comments: Given a situation where the same decision is in need of support, but the information presented to the platform manager shows to be a bit different. This is illustrated in Table 5.4 below.

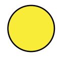
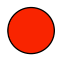
Criteria related to	**Criterion No.**	**Given information / Assessment**	**Rated compliance**
Barriers	1	- Barrier panel shows important technical safety barriers out of operation - Consideration of organisational barriers shows lack of competence in the crew performing the work.	
	2	- No temporary replacement barrier can be established for the technical barrier out of operation. -Additional amount of personnel performing the activity may compensate for lack of competence.	
	3	N/A	N/A

Table 5.4: Alternative rating of compliance when given another status of the safety barriers

Table 5.4 illustrates how the decision-making process can be stopped at an early sign of unacceptable compliance with decision-making criteria, which in this scenario are criteria related to safety barriers. Even though temporary replacement barriers can be established for the organisational barrier *competence*, the platform manager is not capable of establishing temporary replacement barriers for technical safety barriers out of operation. Thus, the degree of compliance with the decision criteria regarding requirements of safety barriers stipulate that hot work is not to be performed. Whether or not other criteria can be fulfilled can in this decision-making scenario thus be considered as somewhat irrelevant.

6 DISCUSSION

6.1 Introduction

This chapter contains a discussion of the results of this thesis in general and in relation to the topic of the master's thesis. The following subchapters present a discussion upon operational safety, the purpose of the outlined risk control tool, an alternative approach to the risk control tool, risk estimation, decision-making criteria, presented indicators, safety barriers and classification, availability, quality and presentation of data, what the suggested solution covers and, finally, strengths, weaknesses and challenges with the outlined risk control tool.

6.2 Operational safety

The matter of occupational risk versus major accident risk is covered extensively in literature. Both the Macondo disaster in 2010 and the Texas City refinery explosion in 2005 showed signs of misconception in the industry on how to manage major accident risk (Vinnem, 2013a). It is found that operational control of major accident risk is directly linked to barrier management. This can be stated, as the process of barrier management includes the establishment of barriers and the activities needed to maintain the barriers' function throughout the facility's lifetime (PSAN, 2013), and because accidents happen "when Barriers become Degraded" (Våge, 2012).

Furthermore, DNV (2012a) states that most accidents today primarily result from inadequate operational safety. This claim can be said to be supported by PSAN (2011a) which, as stated in chapter 3.4.1, has identified the need to develop new tools for risk management. It is here the risk control tool discussed in this thesis fits in.

6.3 The purpose of the risk control tool

One of the important questions attempted answered in this thesis is about how the platform manager can use information on the state of the safety barriers as a risk control tool. Regulatory requirements, as those presented in chapter 2.5, have to be considered and addressed in relation to *barrier management* and a *new risk control tool*. Many of the presented regulations cover requirements of and to safety barriers specifically. § 5 of the

Management Regulations requires that "It shall be known which barriers are not functioning or are impaired" (PSAN, 2012b). It is thus required by regulations that the state of the safety barriers is known. Interviews performed, for the sake of this thesis, of two former platform managers and an executive vice president have shown that the most important decisions the management of the platform makes, where the status of the safety barriers are of importance, are during the planning of activities (Ertsaas, 2013, Olsvik, 2013 and Michelsen 2013a). More specifically the most important decisions are related to all activities involving gas carrying systems and/or equipment. It is thus suggested that a new risk control tool providing decision support, including information on the state of the safety barriers and criteria, to situations where the management of the platform are to decide whether or not an activity can be performed is suitable. The platform manager can thus use information on the state of the safety barriers as a risk control tool. This suggested solution is thought to coincide well with what Hayes (2012) found in a case study. Hayes (2012, p. 431) found that the operational managers limit "activities to within the limits of the remaining barriers" or "provide a temporary replacement barrier which might be increased monitoring by the operational team".

The aforementioned tool could also be capable of providing decision support during the long term planning performed by the management and support staff onshore (Vinnem, 2013c), and could also be used to monitor factors that are presented through the tool. NORSOK Z-013 (2010), as stated in chapter 3.2, presents a range of situations and activities associated with a temporary increase of risk. While not all situations and activities presented may be covered by the risk control tool, e.g. drifting objects and man over board etc., it is suggested that the risk control tool is focused on providing decision support on a day-to-day basis to the platform manager, as well as to the onshore management, during the planning of activities on the installation, where the information of safety barriers' condition is of importance (Ertsaas, 2013 and Michelsen, 2013a). This suggestion also coincides well with the fact that barrier management and operational control of major accident risk is directly linked.

6.4 Alternative approach

The "Living Risk Analysis" proposed by Vinnem and Haugen (2012) can be seen as an alternative approach to the risk control tool outlined in this master's thesis. Vinnem and Haugen (2012, p. 1) state that the living risk analysis has the purpose of acting "as a better tool for decision support in operations of a process plant". Furthermore, the living risk analysis has the overall objective to "Provide input to relevant decisions relating to planning and execution of maintenance and operational issues" (Vinnem and Haugen, 2012, p. 3). Thus, this approach is considered to coincide well with the purpose of the risk control tool outlined in this master's thesis. The proposed "living risk analysis" is not discussed more thoroughly in detail in this master's thesis, as it has not yet been made public and because the authors do not want that information to be shared at this time.

6.5 Risk estimation

It is suggested that a new risk control tool should be focused on bridging gaps found in the industry it is intended for. The supervisory activity carried out by Vinnem et al. (2010) for PSAN in 2009 showed that the current risk analysis studies employed by the sector were not utilised "as input to day-to-day decisions on installations/plants about minor modifications, maintenance and intervention activities" (Vinnem and Haugen, 2012, p. 4). Vinnem and Haugen (2012) suggest, as aforementioned, that a possible solution can be a "Living risk analysis", using what can be classified as "heavier" QRA methods to provide decision support to the aforementioned decisions. As discovered by Hayes (2012, p. 431), operational managers do not use a framework of indentifying hazards and consideration of consequences and likelihood, but rather focus on the "barriers that had already been put in place". This "barrier approach" is found to be preferred over risk management as a decision-making frame, as it is linked "directly to the current state of the operational system" (Hayes, 2012, p. 431). As discussed in chapter 3.9, the risk control tool outlined in this thesis is suggested to provide certain decision making criteria for the activities that are not permitted, also including criteria related to information on the state of the safety barriers. However, one of the criteria proposed are linked to a maximum risk level that should reflect the type of activities that are to be undertaken. Fløtaker (2013a) states that a new risk control tool, aimed at providing decision support to the platform manager, should be easy to use and should not require that that the platform manager carry out a complex risk analysis. This does not exclude the fact that a risk control tool can have capabilities built into it that can give a reasonable estimate of risk over shorter time duration, like the risk management tool used at Kårstø gas plant. Furthermore, Vinnem (2013d) state that a heavy model can be applied as long as the user interface has a low "user threshold". Moreover, if the risk control tool is to include a function similar to the risk management tool used at Kårstø gas plant for calculating short-term risk, the challenges related to the model used in the Kårstø risk management tool should be addressed. These challenges are presented in Table 6.1.

Choice of parameters	Simplified risk model	Use of results
• "Locked" and "free" parameters • Easy to use by "non-risk analyst" • Usability vs. complexity	• Changes in consequence not reflected • Stretches the area of validity of the risk analysis	• Accuracy of "part results" • Necessary to assess the total risk • Measuring against acceptance criteria

Table 6.1: Challanges related to the risk management tool used at Kårstø gas plant, based on Statoil (2011)

If the risk control tool is not capable of incorporating a function for estimation of risk over shorter time periods, DNV states that criteria related to a maximum activity level could be used (Fløtaker, 2013b).

Chapter 2.2 presents two definitions of the term risk, stated by Rausand (2011) and ISO 31000 (2009) respectively. Both definitions are found to state that risk is about something that might occur (in the real world). On this basis, uncertainties should be included when calculating the risk, as no calculation can be undertaken that can be said to express the state of the real world a 100 % precisely and certainly not without including uncertainties. The most common perspective on risk used in the offshore petroleum industry, the expected value, does not include uncertainties. Uncertainty is however, as stated in chapter 2.2, included in the (A,C,U) perspective (Aven, 2008). Thus, if the risk control tool outlined in this master's thesis is to incorporate a function for calculating the total risk of the platform, the perspective of risk to be used is suggested to include uncertainties. Furthermore, Fløtaker (2013e) states that uncertainty is, in practice, not included due to the fact that the calculated risk is an estimate in itself. However, a sensitivity analysis may be performed to give a conservative level of risk (Fløtaker, 2013e).

Furthermore, if the risk control tool is to incorporate a function for calculating the total risk of the platform, the risk control tool must capture short-term transient levels of risk, in addition to risk peaks. As stated in chapter 3.9, the "acceptance limits for the most exposed individuals are usually around FAR = 25-30 (per 10^8 exposure hours)" (Vinnem and Haugen, 2012, p. 12). It is expected that the FAR-values for activities with shorter time duration exceed this limit. It is thus suggested, as discussed in chapter 3.9.2, that the proposal by Vinnem and

Haugen (2012) be followed, implying that such limits are restrained from being called "risk acceptance limits", and rather be called "tolerance limits" as this is "a more flexible term" (Vinnem and Haugen, 2012, p. 12). Furthermore, the establishment of a tolerance limit of risk for short-term activities is thus needed, if the tool is to incorporate such a function. This is addressed in chapter 3.9.2.

The total risk of the platform can also be considered against acceptance criteria for risk using the method presented by Thomassen and Sørum (2002). The total risk of the platform would, in this case, not rely specifically on activities, but on the condition of the safety barriers/-systems. This method is, however, considered to be too time consuming to use in view of the purpose of the risk control tool outlined in this master's thesis.

6.6 Decision-making criteria

The interviews performed of the aforementioned former platform managers and the executive vice president also revealed that platform managers make a variety of considerations when deciding whether or not activities can be performed. Such considerations include, amongst other, simultaneous activities, mapping of the activity on drawings of the installation and the use of best practice, in addition to a consideration of the condition of the safety barriers/-systems (Ertsaas, 2013, Olsvik, 2013 and Michelsen 2013a). In addition, the research performed has shown that it is not sufficient to solely base the decision on whether or not to perform an activity on the basis of safety barriers' condition. On this basis it is suggested that a practicable solution is to present a range of decision-making criteria, in addition to guidance on how criteria are to be assessed, to the decision-maker(s). The criteria presented in this master's thesis are thought to fit well with the considerations, stated by Ertsaas (2013), Olsvik (2013) and Michelsen (2013a), that must be made during planning of activities on the installation.

6.7 Presented indicators

DNV states that criteria also can be established for all indicators that are important and relevant for the purpose and that can be controlled / managed upon (Fløtaker, 2013b). Chapter 4 presents a range of indicators that can be used for this purpose. It is however, as stated by Vinnem (2010, p. 781), important that the indicators used are not "over-focused on the need to be able to measure" but that attention is focused on "intuitiveness, reflection of hazard mechanism, robustness to manipulation and validity for major hazard risk". Moreover, the risk control tool should rely on a limited number of indicators, as stated in chapter 3.4.2. It is therefore suggested that the indicators are limited to a reasonable number, and that the chosen indicators fit the purpose of the risk control tool, are recognisable for decision makers and fitting to the installation. Furthermore, certain aspects regarding the use of a technical integrity indicator should be considered. Refsdal (2011) has stated the following arguments in favour and against using a technical integrity indicator, as presented in Table 6.2.

Pros	Cons
• Provides incentives for continuous improvement • Highlights the "best in class" -> experience transfer and learning • Provides decision support for prioritisation	• May camouflage important issues through aggregation • May turn focus to the indicator itself rather than underlying issues and improvement actions • May give better grade than without KPI to appear good (or worse grade to get more resources)

Table 6.2: TI indicator - Pros and cons, based on Refsdal (2011)

6.8 Safety barriers and classification

Chapter 4 presents a range of safety barriers/-systems as for instance stated in regulations (PSAN) and NORSOK S-001 and Z-013. However, the presented barriers/-systems cannot be said to paint the complete picture of the safety barriers/-systems implemented on platforms on the NCS. In addition, implemented safety barriers may vary from platform to platform. It is thus important that the risk control tool is adapted to the installations it is intended for. It is thus also suggested that efforts be made to be able to present detailed installation-specific information of the condition of the safety barriers/-systems. Chapter 4 also presents RIFs, in addition to the aforementioned safety barriers/-systems. It is found that RIFs can be defined as factors that have an indirect effect "on the occurrence and/or consequences of an undesired event or accident" (Sklet 2006, p. 496). These differ from barriers that ought to "have a direct and significant effect" (Rausand, 2011, p. 496). Furthermore, a comparison between the organisational and operational barrier elements presented in chapter 4.2.3 and the RIFs presented in Table 4.4, shows a striking similarity. It is therefore suggested that focus should be made on safety barriers and not on RIFs.

The literature study performed for this master's thesis has also shown that there are several ways of classifying safety barriers, one of them being the classification proposed by Sklet (2006) where barriers are classified by system. To manage major accident risk on a day-to-day basis, the risk control tool must be capable of capturing and showing the short-term transient behaviour (or state) of the safety barriers/-systems. It is thus suggested that a classification of barrier elements according to their transient properties / behaviour could be the solution, as addressed in chapter 3.12. Vinnem (2013a) states that such a classification has not been developed. It is thus also further suggested that a complete classification of safety barriers according to their transient properties / behaviour to be developed. It should, however, be noted that this does not mean that focus should be removed from long-term weaknesses, as it is important to have control on long-term weaknesses (Fløtaker, 2013d).

6.9 Availability, quality and presentation of data

An important note is that if the risk control tool is capable of presenting information as discussed in chapter 3.9 and 3.10, the risk control tool could also be used to monitor factors that are presented through the tool in addition to provide decision support. A more important note is the matter of availability of information, and the matter of automatically conveying information to the user(s) of the tool. As discussed quite extensively in chapter 3.11, there are a lot of information that is required as input for such a risk control tool, and such a risk control tool will also have to rely on quite a comprehensive source base. Sources of information include performed QRA's, maintenance programs, audits and inspection programs, operational data, accidents and incidents, dispensations, training and so forth. As presented in chapter 4.8, the energy company Statoil has already incorporated a tool, TIMP, that collects information from other data sources, and further presents a rating of each PS in addition to an overall technical integrity indicator. Other operators have, as shown in chapter 4.7, for instance established a barrier performance panel. The availability of information, and the detail and quality of this information, will thus vary from operator to operator, and from installation to installation. Moreover, the risk control tool may thus require more information than what exists and is available and accurate enough from each operator and/or installation, an example of this being the availability of area specific barriers' condition. It is thus required that systems be established from which the risk control tool, outlined in this master's thesis, can collect the necessary data and information.

It is important that the collected data and information is systemised and made available and easily understandable to reduce the time required to perform the judgement call, on whether or not to perform an activity, to as limited as possible. Vinnem (2013a) states that WP meetings of approx. one hour duration are held on a daily basis, and that there typically are 50-60 WPs that are being approved in such a meeting. Thus, the time available for judgement upon each single WP is fairly short. Vinnem (2013a) states further that in periods with high activity level on an installation, the time available to decide whether or not an activity can be performed is, naturally, even further reduced. It is thus necessary to create an interface that is easy to use and that is capable of presenting the required information upon request.

6.10 What the suggested solution covers

The thesis explores and describes how barrier management can be directly linked to operational control of major accident risk, and the risk control tool outlined in this master's thesis covers decision-making support related to planning of activities on the installation. Moreover, the thesis covers important aspects regarding risk and barrier management, the premises for a new risk control tool, existing measures, methods and tools, and decision-making support on the installation. However, the suggested solution does not include visual design of the risk control tool, or a complete development of such a tool. Furthermore, the suggested solution does not cover support after an initiating or accidental event, nor does it include decision support regarding other types of activities and decision-making questions as for instance finances, maintenance and inspection intervals etc. Moreover, the master's thesis is focused on decision-making and support on the installation for offshore personnel, which in turn means that planning of activities offshore by onshore personnel is less covered. The suggested solution can in addition not be said to paint the complete picture of all aspects regarding e.g. risk and barrier management, major accident risk, operational safety, safety barriers and existing measures, methods and tools. The suggested solution is, however, thought to coincide well with the proposed purpose of the new risk control tool which, in chapter 3.3, was stated to be a new risk control tool that provides decision support on a day-to-day basis by helping the decision-makers decide whether or not activities can be performed.

6.11 Strengths, weaknesses and challenges with the risk control tool

Summing up the discussion, it is clear that there are in fact some strengths, weaknesses and challenges with the risk control tool outlined in this master's thesis.

Strengths include:

- Do not underestimate the importance and value of the platform manager's and/or other decision-maker's knowledge and judgement.
- Can be used in more occasions / to more activities than a "one criteria" method.
- Focus on major accident risk.
- It should be easy to include more factors affecting the decision.
- Easy to use on a day-to-day basis.
- Provides a good decision basis.
- Fits well with the "barrier approach" used by operational managers, as discussed in chapter 2.10.
- May save time during decision-making.
- May be used to monitor factors of importance.

Weaknesses and challenges include:

- Availability of needed, high quality, up to date and detailed information and data.
- Must be tailored to each platform / installation.
- Require quite a comprehensive information base.
- A function for calculating the total risk of the platform may turn out to be to time-consuming and complex to be used by a platform manager during operational decision-making.
- FAR-values for activities with shorter time duration may exceed RAC. Thus, short-term tolerance limits for risk need to be established.
- May require that current QRAs include more factors, especially "factors influencing the probability of major accidents" (Vinnem and Haugen, 2012, p. 5).
- May prove to be time-consuming and costly to develop.
- May require extensive upkeep to be maintained.
- One often finds resistance among employees when introducing new tools (Michelsen, 2013a).

7 CONCLUSION AND RECOMMENDATIONS FOR FURTHER WORK

7.1 Conclusion

Based on the presented examinations, it has been found that operational control of major accident risk is directly linked to barrier management, as the process of barrier management includes the establishment of barriers and the activities needed to maintain the barriers' function throughout the facility's lifetime (PSAN, 2013), and because accidents happen "when Barriers become Degraded" (Våge, 2012).

Interviews performed, for the sake of this master's thesis, have shown that the most important decisions the management of the platform makes, where information on the safety barriers' condition is of importance, are related to the planning of activities on the installation (Ertsaas, 2013, Olsvik, 2013 and Michelsen 2013a). It has furthermore been found that risk considerations performed during planning of activities include, but are not necessarily limited to (Ertsaas, 2013, Olsvik, 2013 and Michelsen 2013a):

- Focus on the condition of the safety barriers, and that the needed barriers are in place.
- Plant status.
- Simultaneous activities.
- The disconnection of barriers like bypassing gas detection or fire detection systems.
- Extraordinary measures.
- Mapping on drawings of the installation of the activities that are to be performed.
- The use of best practice, as for instance Statoil's A-standard.

In addition, it has been identified a need to develop new tools for risk management (PSAN, 2011a and Vinnem et al., 2010). It is thus suggested that a suitable solution is a new risk control tool that has the purpose of providing decision support, including, amongst other, decision-making criteria and information on safety barriers' condition, to situations where the management of the platform is to decide whether or not an activity can be performed.

It is further suggested that a new risk control tool is focused on bridging gaps found in the industry it is intended for. It is thus also further suggested that a new risk control tool is focused on providing decision support on a day-to-day basis to platform manager(s), during planning of activities on the installation where the information of safety barriers' condition is of importance. The platform manager can thus manage major accident risk by using, amongst other, information on safety barriers' condition as a risk control tool.

It is, in relation to decision support, suggested that the user(s) of the tool be presented with the following:

- Area specific information on the state of the safety barriers that are directed specifically against major accidents.
    - Relevant indicators and information that is suitable for helping the decision-maker make a decision, e.g. valve status (open / shut) from automatic transponders (Fløtaker, 2013d and Vinnem, 2013c).
- A "map" of the platform
    - with a break down structure, or "zoom function", as follows: the installation – deck – area – system. Each level being able to show different kind of information.
    - that should be able to amongst other show P&ID drawings etc
    - showing active dispensations
    - showing work / activities that are in progress, and work / activities that are to be performed. This work can be colour coordinated with for instance hot work and high risk activities and/or work being red, and cold work and all other activities and/or work being blue.
    - displaying the number of activities in the same area
- Current weather and weather forecast.
- Operational data.
- Operating limits and preconditions used in QRA.
- Preconditions stipulated and risk considerations performed during the onshore planning of activities.
- Decision-making criteria and guidance.
- Ideally, a simulation function for which the user(s) can simulate the effect a specific activity brings in time and space (Fløtaker, 2013a).

- The overall risk of the platform. A function within the risk control tool enabling the user(s) to consider the total risk of the platform against tolerance limits for risk, given that such a model can be developed.

It is suggested that the indicators, mentioned in the list above, are limited to a reasonable number, and that the chosen indicators fit the purpose of the risk control tool, are recognisable for decision-makers and fitting to the installation.

For the tool to provide installation specific day-to-day decision support, it is important that the information input to the tool as well as the information displayed to the end user is valid at installation level and is up to date. Implemented safety barriers may vary from platform to platform. It is thus important that the risk management tool is adapted to the installations it is intended for. It is thus also suggested that efforts be made to be able to present detailed installation specific information of the condition of the safety barriers/-systems. Moreover, to manage major accident risk on a day-to-day basis, the risk control tool must be capable of capturing and showing the short-term transient behaviour (or state) of the safety barriers/-systems. It is thus suggested that a classification of barrier elements according to their transient properties / behaviour could be the solution. Moreover, operational barriers are barriers that do not show the same transient or dynamic behaviour as technical and organisational barriers (Vinnem, 2013a). It is thus suggested that focus is on technical and organisational safety barriers.

The tool itself is suggested to be a robust information surface with an interface that is built up like other tools used in the industry or the specific company it is intended for. In addition, the following suggested generic user expectations have been established for the tool that is to be used on a day-to-day basis:

- The tool should cause limited extra work.
- Not a new reporting tool.
- The tool presents a limited amount of indicators.
- The user should be able to "simulate" responses to activities.
- Information on dispensation handling can be displayed.
- Maintain user history.

Furthermore, the aforementioned tool can also be capable of providing decision support during the long term planning performed by the management and support staff onshore (Vinnem, 2013c), and can also be used to monitor factors that are presented through the tool.

It is also suggested that a new risk control tool should, as far as possible, rely on and take advantage of frequently updated and reliable information from other systems already put in place by the operator. Sources of information are found to include; performed QRAs, audit-, inspection-, and maintenance programs, operational data, tools for incident / accident reporting, tools for registration of dispensations, work permits, training and exercise and also the planning performed onshore.

It is furthermore suggested that a practicable solution is to present a range of decision-making criteria to the decision-maker(s), in addition to guidance on how criteria are to be assessed. The aforementioned criteria, to be used when deciding whether or not an activity can be performed, are proposed to be:

- Requirements of and to needed safety barriers' function fulfilled
- Requirements of temporary replacement barriers fulfilled
- Are the temporary replacement barriers "good enough"?
- Not in conflict with a set maximum activity level
- Not in conflict with simultaneous activities on / with the same equipment / system
- Not in conflict with simultaneous activities on the installation, deck or area
- Within restrictions related to weather window
- Not in conflict with information on dispensations
- Not in conflict with operational factors or requirements, like max. pressure, temperature and time
- Not in conflict with operating limits or preconditions used in QRA
- Not in conflict with preconditions stipulated and risk considerations performed during the onshore planning of activities
- Not in conflict with established max. risk level

The max. risk level, as (also) mentioned in the list above, can be included if the risk control tool incorporates a function for calculating the total risk of the platform that can be considered against tolerance limits for risk. This function is suggested to be similar to the one implemented at Kårstø gas plant. If such a function is to be incorporated into a tool for an offshore installation, it is suggested that the function should take into it the most important offshore indicators. An alternative method to the risk management tool used at Kårstø gas plant is the "Living Risk Analysis" proposed by Vinnem and Haugen (2012). It is, either way, important that the applied model fits the purpose of the risk control tool, and is capable of showing transient levels of risk over shorter periods of time. Such a requirement has to be made so that short-term risk and short-term risk peaks can be captured. Short-term transient levels of risk also require that short-term acceptance limits of risk be established. It is also further suggested that the phrase "tolerance limits" is used when addressing short-term risk, rather than "risk acceptance limits", as proposed by Vinnem and Haugen (2012).

7.2 Recommendations for further work

This master's thesis has explored, described and outlined important premises for a new risk control tool to be used in the operational phase, but a complete risk control tool has not been developed. In order for further development of such a risk control tool, the following further work is recommended:

- The establishment of "tolerance limits" for risk for short-term activities.
- Development of a complete classification of safety barriers according to their transient properties / behaviour.
- Development of a tool, as the risk management tool used at Kårstø gas plant, for calculating the risk of a platform.
- Further development of decision-making criteria, including indicators as for instance those presented in chapter 4.
- Further development of guidance on how criteria are to be assessed.
- The creation of an interface that is easy to use and that is capable of presenting the required information upon request.

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Cover image:

Image by Statoil. Statfjord A.

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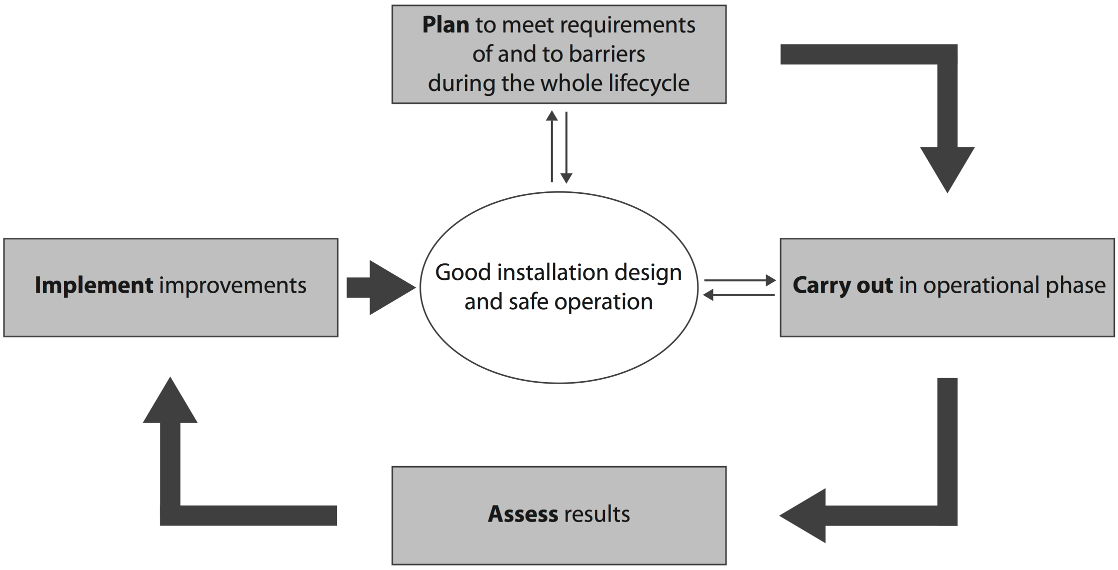
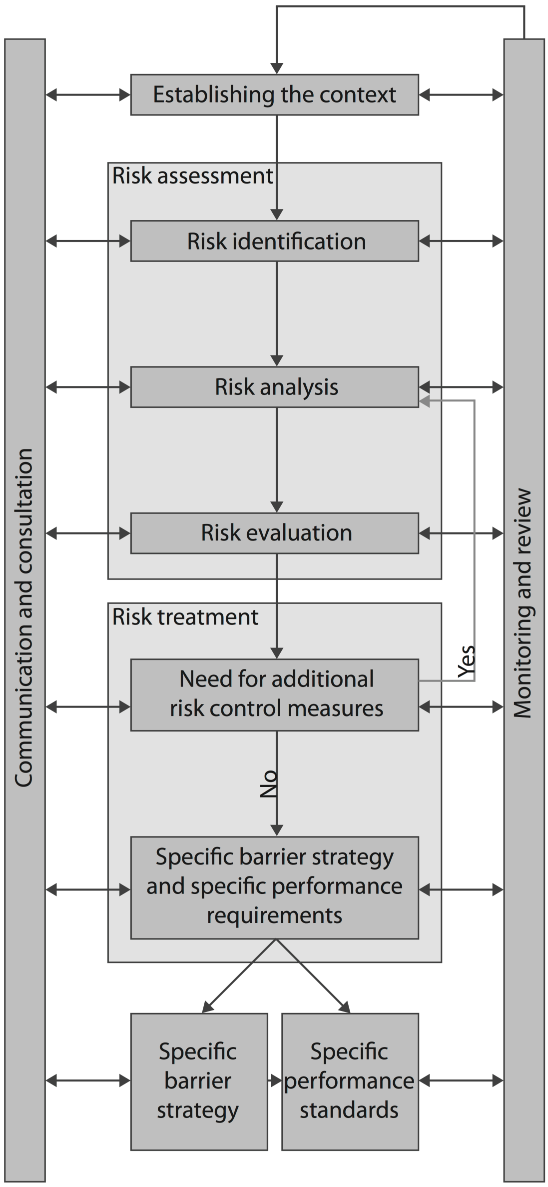
APPENDICES

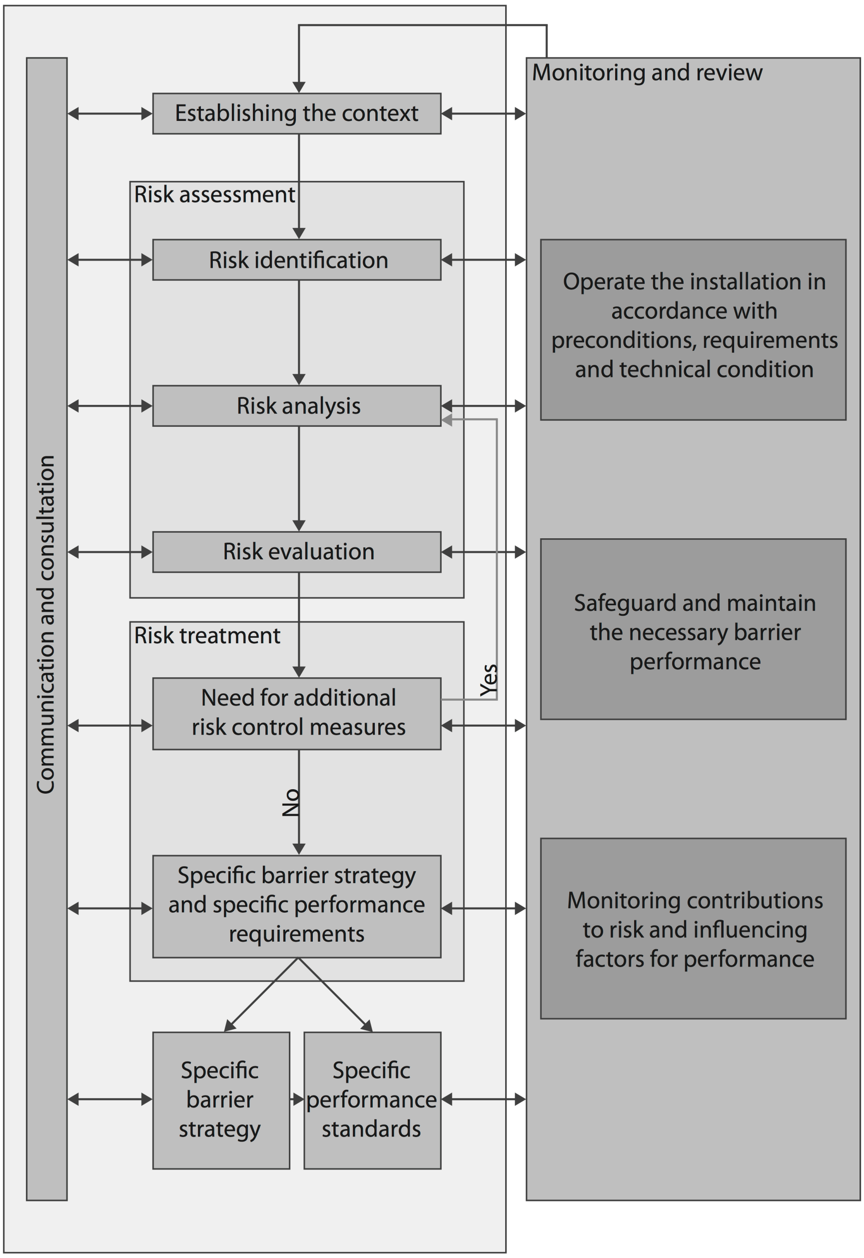
Appendix A – Framework and parts of the process of barrier management



Framework for barrier management, based on PSAN (2013)



Process of barrier management in a planning phase, based on PSAN (2013)



Process of monitoring and review, based on PSAN (2013)

Appendix B – Work Permit form level 1

bp WORK PERMIT no.:

Area (sketch/description) N

LEVEL 1
- ❑ Hot work class A
- ❑ Hot work class B
- ❑ Entry (confined space)
- ❑ Isolation of safety system
- ❑ Pressure testing
- ❑ Work above sea
- ❑ Dangerous substances
- ❑ Radioactive materials
- ❑ Well operation
- ❑ Explosives
- ❑ Critical lifting operation
- ❑ Other/critical operation
- ❑ Work on hydrocarbon system

LEVEL 2
- ❑ Work level 2

1

Applicant name: ______ Discipline: ______ Phone: ______
Work description: ______
Task: ______
Equipment/tools: ______
Installation: ______ Location/module: ______ Deck: ______
Tag/line no.: ______ Zone: ______
Attachment: ______

❑ SAFE JOB ANALYSIS, NO.:
❑ REQUIRES APPROVAL FROM ELECTRICAL DEPARTM.
WORK ORDER NO.: ______
OPERATION NO.: ______
❑ ISOLATION NO.: ______
❑ Day ❑ Night ❑ Ongoing work
From date/hr. To date/hr.

Extended to hr.:
Area/Operations Supervisor *Sign.:*
CCR Technician *Sign.:*
Area Technician *Sign.:*

OPERATIONS- AND SAFETY PREPARATIONS

A

Required	Performed by area technician	*Signature*
❑ Depressurization		
❑ Draining/emptying		
❑ Cleaning/gasfreeing		
❑ Isolation by singel valve/double block and bleed		
❑ Isolation by blind/isolation plan		
❑ Safety tag/lock		
❑ Venting/Extra ventilation		
❑ Prevent release of oil/gas in the area		
❑ Measures against radioactive radiation		
❑ Inspection of the area every.............hour		
❑ Other		

2

GAS MEASUREMENTS PRIOR TO/DURING THE WORK
- ❑ Hydrocarbons every.............hour ❑ H_2S every ....hour
- ❑ Oxygen every ....hour ❑ .... every..........hour

ISOLATION SAFETY SYSTEM ❑ Locally ❑ CCR

System: ______
Location/area: ______
Compensating measures: ______

B

Required	Performed by executing skilled worker	*Signature*
❑ Portable gasdetector no.:	on the worksite	
❑ Verify mechanical isolation		
❑ Electrical isolation/locking Tag no.:		
❑ Fire extinguisher/fire prevention		
❑ Welding machine safely located and earthed		
❑ Continuous guard/radio communication		
❑ Drains blocked/covered		
❑ Barrier/warning signs/PA-announcement		
❑ Cooperate with CCR/Area technician		
❑ Follow requirements for work above sea/at height		
❑ Chemical data sheet known and available		
❑ Procedures/cheklist for the operation known Ref.nr.:		
❑ Control of temporary lifting equipment		
❑ Follow requirements for Entry (confined space)		
❑ Special personal protective equipment		
❑ Measures to avoid work related deseases		
❑ Other requirements/preparations		

APPROVAL / AUTHORIZATION

3

Area/Operations Supervisor	*Other position:*	*HSE function:*	*Platform manager:*

Remarks/requirements:

PRECAUTIONS PRIOR TO / DURING WORK EXECUTION

A

Safety system isolated/reactivated	*Signature:*
Isolated locally/CCR	
Reinstated locally/CCR	
Remark:	

B

Gas test- value						
HC						
O_2						
H_2S						
Time/sign.						

4

Work site cleared according to requirements
Area Technician *time:* *Signature:*

The work is cleared with CCR
CCR Technician *time:* *Signature:*

Precautions understood and are/will be fulfilled
Executing skilled worker *Name: (block letters)*

COMPLETION

A

All locks/tags removed ❑ Yes ❑ No
Equipment ready for operation ❑ Yes ❑ No

5

Area Technician *time:* *Signature:*

Work cleared by CCR
CCR Technician *time:* *Signature:*

B

❑ Work completed ❑ Work not completed
❑ Work place cleaned and secured
Executing skilled worker *Signature:*

Original: Work site
Copy:

www.grafo.no

Reference: BP Norway (2013)

Appendix C – Work Permit form level 2

bp WORK PERMIT no.: LEVEL 2

1

Applicant name:________________ Discipline: __________ Phone: __________

Work description: ____

Task: ____

Equipment/tools: ____

Installation: ________________ Location/module: ______ Deck: __________

Zone: __________

❑ SAFE JOB ANALYSIS, NO.:
❑ REQUIRES APPROVAL FROM ELECTRICAL DEPARTM.

WORK ORDER NO.: ________________
OPERATION NO.: ________________
❑ ISOLATION NO.: ________________
❑ Day ❑ Night
From date/hr.

Tag/line no.:

Attachment:

2 OPERATIONS- AND SAFETY PREPARATIONS

A

Required	Performed by area technician	*Signature*
❑ Depressurization		
❑ Draining/emptying		
❑ Cleaning/gasfreeing		
❑ Isolation by singel valve/double block and bleed		
❑ Isolation by blind/isolation plan		
❑ Safety tag/lock		
❑ Coordinate with other activities		
❑ Inspection of the area every.............hour		
❑ Other		

Remarks:

B

Required	Performed by executing skilled worker	*Signature*
❑ Verify mechanical isolation		
❑ Electrical isolation/locking		
Taag no.:		
❑ Barrier/warning signs		
❑ Cooperate with CCR/Area technician		
❑ Procedures/cheklist for the operation known		
Ref.no.		
❑ Control of temporary lifting equipment		
❑ Special personal protective equipment		
❑ Measures to avoid work related deseases		
❑ Other requirements/preparations		

3 APPROVAL / AUTHORIZATION

Area/Operations Supervisor: / *Other position:*

Remarks/requirements:

PRECAUTIONS PRIOR TO / DURING WORK EXECUTION

A

Work site cleared according to requirements
Area Technician *time:* *Signature:*

The work is cleared with CCR
CCR Technician *time:* *Signature:*

B

Precautions understood and are/will be fulfilled
Executing skilled worker *Name: (block letters)*

4 RENEWED WORK CLEARANCE / TEMPORARY TERMINATION

Renewed work clearance

Date/time	Area Technician	Executing skilled worker	CCR Technician

Temporary termination of work

Date/time	Area Technician	Executing skilled worker	CCR Technician

5 COMPLETION

A

All locks/tags removed ❑ Yes ❑ No
Equipment ready for operation ❑ Yes ❑ No
Area Technician *time:* *Signature:*

Work cleared by CCR
CCR Technician *time:* *Signature:*

B

❑ Work completed ❑ Work not completed
❑ Work place cleaned and secured
Executing skilled worker *Signature:*

Original: Work site
Copy:

Reference: BP Norway (2013)